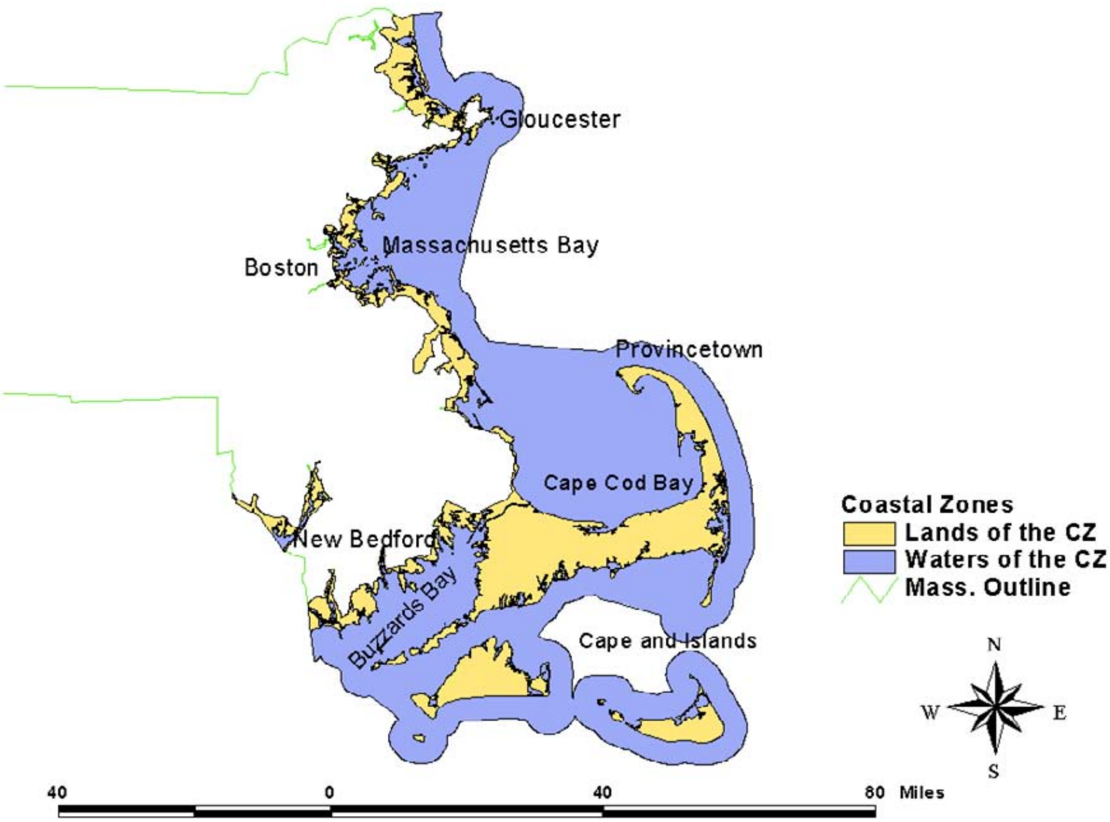
Strategic Plan for Mapping Massachusetts' Benthic Marine Habitats



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1. Executive Summary

The distribution, types and quality of subtidal marine habitats are largely unknown in shallow waters throughout Massachusetts' marine environment. This lack of information hinders the management of marine ecosystems. An essential component of effective management is knowing where distinct habitats occur so that exemplary, unique, productive and sensitive habitat types can receive a higher level of resource assessment for permit review or even be subject to proactive protection measures. This strategic plan addresses the need to conduct coordinated, comprehensive mapping of Massachusetts' benthic habitats to improve their management. The technologies used to acquire seafloor bathymetry and sediment texture data are changing rapidly and therefore, the most cost efficient methods to obtain benthic habitat maps are also subject to change as the technology evolves. This strategic plan will remain a dynamic document that will be updated as protocols and technology capabilities progress.

The plan contains case studies illustrating the need for comprehensive benthic habitat mapping and describes how benthic habitat maps would be beneficial to a wide variety of ocean resource stakeholders. Issues that are discussed in this plan include: definitions of habitat and habitat mapping, habitat classification systems, and the intended audience for benthic habitat maps. An overview of related mapping programs in Massachusetts and the region is given. These overviews summarize the currently available spatial data that could contribute to marine resource management decisions and clarify the general lack of habitat related information for the Massachusetts subtidal zone. Federal agencies collect acoustic seafloor data for navigation purposes and there are several existing datasets in Massachusetts that could be utilized for benthic habitat mapping purposes. The geographic locations and types of data are described; as funds become available, these data could be re-processed to determine seafloor sediment distributions.

This document gives a brief overview of the numerous types of equipment that are used to collect benthic habitat related data. The recommendations section describes which types of equipment are most suited for mapping in various water depths. A detailed protocol for groundtruth sampling is provided along with recommended data classification and analysis procedures. Cooperation between government, academic and private groups will be required to efficiently accomplish state-wide benthic habitat mapping; potential partnerships and collaborations are identified to insure that mapping utilizes the substantial habitat mapping related technical expertise found in Massachusetts.

Benthic habitat maps are a vital tool to allow managers to visualize the distribution, diversity and extent of marine communities under their jurisdiction, and they will contribute considerably to the comprehensive planning and management of ocean resources.

1.1 Objective

The goal of this strategic plan is to propose a method to conduct coordinated, comprehensive mapping of Massachusetts' subtidal benthic marine habitats. For the purposes of this strategic plan, habitat maps would be composed of the physical (surficial and subsurface geology and water depth) and biological (species composition and relative abundance of both flora and fauna) data necessary to differentiate the spatial distribution of various biological community types. The audience for the plan is the Commonwealth's environmental workforce (government, academia, non-governmental organizations, contractors) while the audience for the map products will encompass a diverse stakeholder community, including local residents, resource managers, consultants, developers, scientists, fishermen, aquaculturists, and environmental organizations. This strategic plan addresses the need for habitat maps and summarizes important considerations for obtaining such maps for all marine waters under state jurisdiction (Fig. 1). Because seafloor mapping is a rapidly evolving field, it is expected that this plan will remain dynamic as the issues, technologies and management needs change. Research on the importance of various habitat types for the survival and growth of marine organisms is continually supplying marine resource managers with needed information. As the relationships between organisms and their habitat preferences/requirements are elucidated, the types of information collected for benthic habitat mapping may shift. Additionally, the benthic habitat maps will need to be updated on a periodic basis because the myriad physical (e.g. bathymetry, sediment texture) and biological (e.g. presence of vegetation, abundance of key organisms) factors will change with time. This plan addresses some of the pertinent data management issues to insure that the map updates are as seamless as possible.

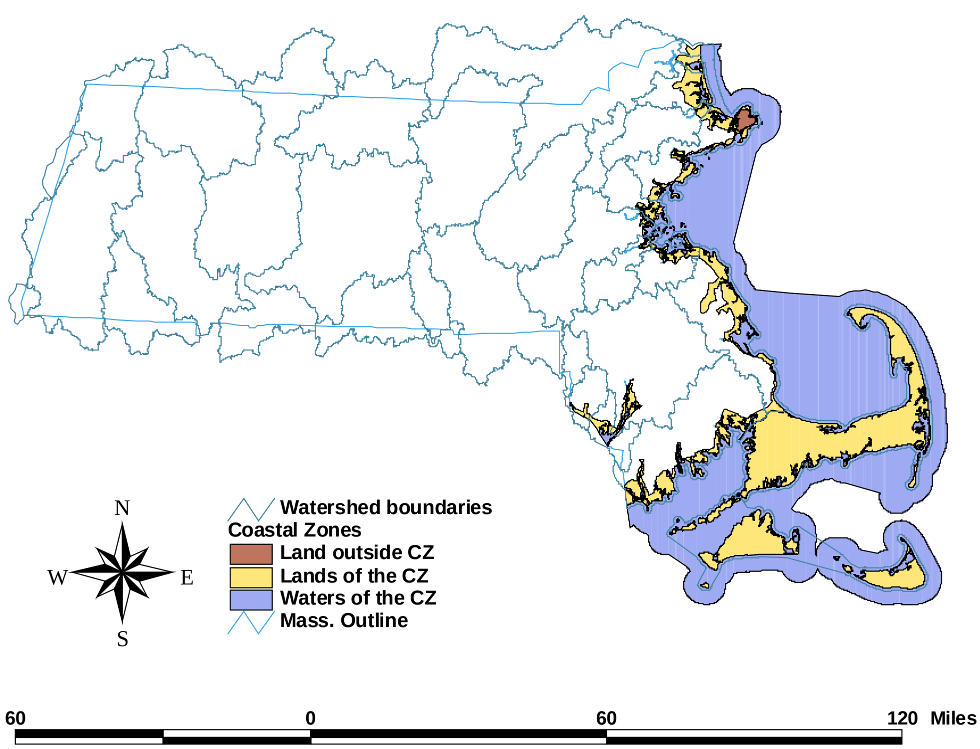

Figure 1: Map of Massachusetts showing waters and lands of the coastal zone with watershed boundaries. Coastal Zone (CZ) is a regulatory boundary.

2. Justification

Coastal and fishery resource managers are frequently tasked with making decisions about development projects or uses of the coastal zone and ocean environment without sufficient knowledge of the marine habitat types that may be impacted by proposed projects. Massachusetts is currently facing particularly strong development pressures in the coastal zone (see Fig. 1 for coastal zone boundary). Existing and proposed development projects including aquaculture, wind farms, pipeline and cable installations, construction of docks, piers, sewage outfalls, and discharge of pollutants (e.g., nutrients and heavy metals) can severely disrupt and degrade the habitat functions and values of the nearshore marine environment. Productive habitats for commercially and ecologically valuable species (seagrass, shellfish, juvenile fish) are located throughout state waters and are potentially impacted by these direct and indirect perturbations.

Coastal systems are vital to the sustained health of fishery populations because of the distinctive environmental conditions of shallow waters. These waters provide critically important habitat conditions that furnish spawning sites, support early survivorship and growth, and host a diverse assemblage of commercial and non-target fishes, crabs and mollusks. In addition, several federally endangered and threatened species including birds, reptiles and mammals utilize coastal marine habitats. Furthermore, nearshore waters support and sustain productive shellfisheries, lobster fisheries, anadromous fish runs and historically supported populations of commercially and recreationally important finfish (e.g. Fonesca et al. 1992; Buchsbaum 1997; Deegan and Buchsbaum 1997; Packer and Hoff 1999). The ecological value of these nearshore habitats are also illustrated by the economic benefits they generate. For example, the estimated value of landings in Massachusetts' shellfisheries was approximately 26 million dollars in 1999 (Vin Malkoski, DMF pers. comm.).

Although fisheries managers have considerable information regarding the habitat types that various life history stages of commercially valuable species utilize, little is known about the distribution and extent of these subtidal habitat types. Currently, marine resource managers in Massachusetts only have a very coarse scale map (1:1,000,000) of sediment distribution (Poppe et al. 1989) and often completely lack any information on subtidal resources from which to infer the distribution and/or condition of marine habitats. Higher resolution data on sediment distribution for several selected areas in the Gulf of Maine (e.g. CZM's Gloucester Harbor sediment profile survey, Wilbur 2004) indicate the shortcomings of inferring habitat type at the small scale of the Poppe et al. (1989) map (Fig. 2).

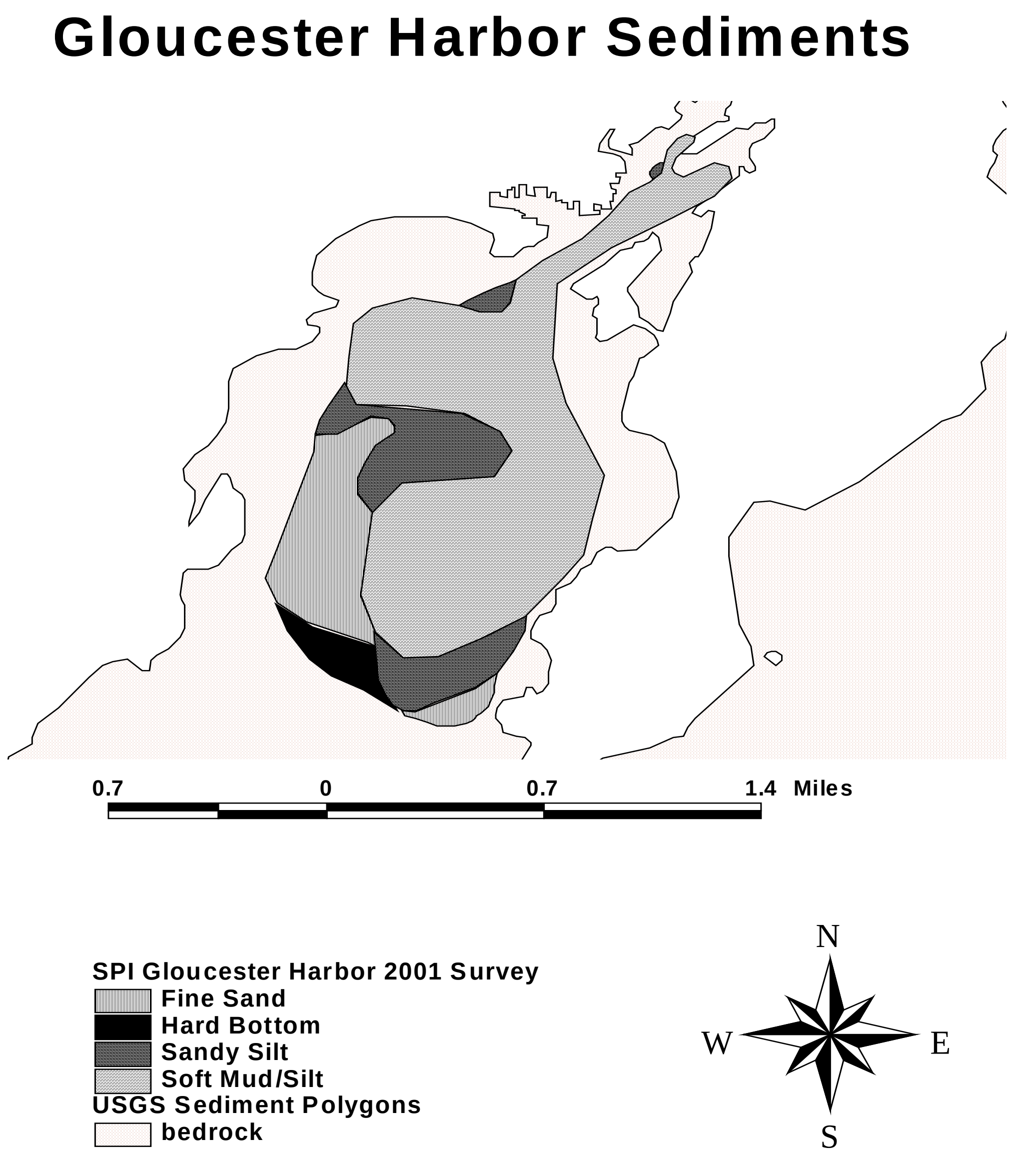

Figure 2: Map comparing sediment types of Gloucester Harbor from two different sampling programs. The polygon from USGS (dotted) represents rock substrates from a 1:1,000,000 map of surficial geology of the Gulf of Maine (Poppe et al. 1989). In contrast, a CZM survey conducted specifically designed to investigate the sediments of Gloucester Harbor indicated a relatively small portion of the seafloor was composed of hard substrates (the sediment profile camera could not penetrate)(Wilbur 2004). The finer sampling resolution of the sediment profile survey provides more detailed sediment distribution information and exemplifies the shortcomings of relying on such a coarse-scale map to infer sediment distribution.

Furthermore, while a map of sediment distribution provides some indication of the types of communities that may be found in a particular location, there can be large variation in community types on similar sediments because of other environmental factors (i.e. currents, temperature, depth, salinity, nutrients, oxygen availability) and the disturbance regime. A terrestrial analogy would consist of deciding if a parking lot could be placed in a particular location that has soil with fine texture but not having any knowledge of the vegetation type or fine-scale topography of the area. This description illustrates that the lack of information regarding the extent and distribution of benthic marine habitats limits the effective management of marine resources in the Commonwealth's waters.

In contrast with marine resource managers, terrestrial and freshwater managers have access to many types of maps that depict information vital to management decisions. For example, the United States Geological Survey (USGS) has created 1:25,000 scale topographic maps of the terrestrial portion of the United States. These maps depict topographic contours, infrastructure, hydrological features and forested areas. Terrestrial resource managers also have access to maps of soil types (USDA and Natural Resources Conservation Service), surficial geology (USGS), exemplary natural communities (Natural Heritage and Endangered Species Program- MNHESP), orthophotograph wetlands and streams (Department of Environmental Protection- DEP) and land use analyses (National Wetlands Inventory). Marine resource managers generally lack this type of information for areas under their jurisdiction unless the site has been examined for a previously proposed project. In the absence of spatially explicit information regarding the resources under their jurisdiction, marine resource managers are forced to rely on site and project specific resource characterizations provided by the applicants to make management decisions and therefore are prevented from long term, proactive planning.

Marine scientists and resource managers have a basic understanding of the values and functions of particular habitat types. For example, seagrass beds are renown for their nursery function for several commercially important fishery species. Deep-water rock ledges often harbor diverse assemblages including soft corals and other long-lived species. However, seagrass beds in Massachusetts have only recently been mapped and the locations of some deep-water rock ledges are known only through research published in scientific journals. Without comprehensive maps of the marine subtidal zone, marine resource managers cannot plan for conservation of unique areas or even assess the relative abundance of various habitat types. By acquiring data on the spatial distribution of marine habitats, marine resource managers could enhance their ability to protect particularly sensitive or productive habitat types.

2.1 Case studies illustrating the need for benthic habitat maps

Increasing development pressures in the coastal zone could lead to the degradation of the quality of the Commonwealth's marine habitat and even the disappearance of particularly sensitive habitat types. Benthic habitat maps could be used to aid in siting and reviewing the environmental impacts of a wide variety of development projects on the seafloor and to reduce the impacts of these types of projects. Below are some case studies that show how benthic habitat maps have or might in the future improve siting of projects, improve fishing efficiency, etc.

Dredging in an eelgrass bed (from Mantzaris 1997)

Benthic habitat maps can help to prevent unintentional destruction of sensitive or productive habitats. In 1992, the town of Swampscott and the Massachusetts Department of

Environmental Management (DEM) requested permission to perform maintenance dredging in two areas of the town's harbor. They were granted permission after the harbormaster reported that there were no shellfish in the project area and the Army Corps of Engineers (ACOE) and the National Marine Fisheries Service (NMFS) did not object to the project. The contractor noticed that he was dredging up eelgrass and that the actual location of the dredging was outside of the area dredged in 1958 (the date of the last dredging). After he contacted the ACOE, a dive survey indicated that eelgrass was present throughout the project area. Approximately two acres of eelgrass bed were lost due to the dredging.

As a result of the loss of eelgrass, the ACOE New England Division and NMFS have agreed to implement a two-tiered approach to marine resource assessment for proposed projects. Tier one projects require applicants to query existing sources to determine which resources may be affected by any proposed project that extends seaward of mean high water. If tier one review is judged to be insufficient in determining the extent of impacted resources, the project will be subject to tier two review. If the project involves dredging, it automatically proceeds to a tier two designation. Tier two review requires resource assessment surveys, especially if shellfish or seagrass may be affected by the project. Benthic habitat maps could have indicated where eelgrass or the appropriate substrates for eelgrass occur to prompt a more detailed assessment of the site's conditions prior to conducting the maintenance dredging.

<u>Offshore wind farm development (Cape Wind Project)</u>

Benthic habitat maps can inform and improve the design of resource assessment surveys, which are routinely conducted to site and evaluate the potential impacts of development projects. The Cape Wind project proposes to build 130 wind towers over 26 miles in Horseshoe Shoals in Nantucket Sound. The towers would be up to 423 feet high and each would have a footprint diameter of approximately 16-21 feet with transmission lines buried below the seafloor running between the towers. The transmission line would pass through state waters and emerge on Cape Cod.

The project proposal generated concern among conservationists and fishermen about the negative impacts of the project on the seafloor habitat. As part of the permit review process, an environmental impact statement (EIS) is being prepared for the proposed windfarm. The project proponents were required to assess the potential impacts of the construction of the towers. Because no habitat maps currently exist for the area, the proponents hired a consulting group to conduct surveys to reveal the range of marine habitats in the project area. If habitat maps were available at the outset, some of the controversy surrounding the proposal may have been diffused, or the preliminary analyses of environmental impact could have focused on the specific communities that occur in the vicinity of the towers. Several additional windfarm energy proposals off the coast of Massachusetts are currently under review, which testifies to the ongoing relevance of this issue for coastal management. Habitat maps of the windfarm area would help managers design surveys that would insure that the windfarm proponents 1) address all of the habitat types in the area, 2) use the proper methodology to characterize the resources and 3) reference baseline conditions for a monitoring program.

<u>Improving commercial fishing efficiency</u> (from Manson and Todd 2000)

The fishery and habitat protection benefits of conducting habitat mapping are exemplified by a cooperative mapping project between offshore scallopers and the Geological Survey of Canada on Brown's Bank, Nova Scotia. The fisheries collapse in Atlantic Canada during the

1990's prompted scallop fishers to seek ways to ensure the stability of scallop stocks. Manson and Todd (2000) describe the process by which four different maps of the seafloor were produced as a result of acoustic surveys combined with extensive groundtruthing. A combination of multibeam sonar, sidescan-sonar and seismic reflection profiling were used to map the bathymetry and the sediments covering Browns Bank. An extensive groundtruthing program of video and still photography, coupled with sediment sampling, followed the acoustic surveys. After data processing and interpretation, four different types of maps were created: (I), the seafloor topography map which acts as the base map for all other information; (II), the multibeam backscatter layer which is a proxy for seafloor sediment type; (III), the surficial sediments and bedforms which were mapped from the geophysical information and sediment samples; (IV), benthic habitat maps which were compiled from the new knowledge of the surficial sediments combined with analysis of the seafloor video and photographs.

The bathymetry layer provided scallop boat captains a three-dimensional view of the seafloor, thus allowing them to avoid boulder fields or other topographic features that could potentially damage scalloping gear. The benthic habitat layer delineated areas of scallop habitat and was evaluated by a cooperative industry-government test scallop tow program on Brown's Bank. The success of the mapping project in helping the scallop fishermen improve their efficiency became immediately evident. After the maps were produced, the captains harvested the same amount of scallops as in previous years by only dragging in 25% of the previous area, thus reducing gear impacts on the seafloor. By focusing their fishing efforts in areas of adult scallop habitat, captains were able to reduce the amount of bycatch of juvenile scallops and non-target species. The average amount of time required for harvesting one ton of scallops decreased from 6 to 2.5 hours. Fisheries managers also benefited from the mapping effort by learning the distribution and extent of probable scallop habitat; they can now estimate productivity at finer spatial scales. The promising results on Browns Bank spurred interest in further mapping, and the Canadian portion of Georges Bank and German Bank were consequently mapped with multibeam technology and similar habitat maps were created.

<u>Guiding fisheries research</u>

Maps of seafloor topography and sediment distribution can be used to examine relationships between commercially exploited species and their physical environment. For example, sediment distribution maps obtained via multibeam sonar have been used to investigate fish/sediment relationships in Stellwagen Bank National Marine Sanctuary. Auster et al. (2001) examined the relationship between sediment distribution inferred from the multibeam backscatter and fish communities in Stellwagen Bank. The fish distribution data was obtained from the NMFS trawls for the Stellwagen region. They found that there were strong correlations between sediment distributions and fish communities and that certain types of fish communities did not occur on distinct sediment types. The authors suggest that the co-occurrence of fish species with strong habitat affinities with other less well known species could be used to infer the habitat requirements of the less well known species. This type of investigation into the relationships between fish and habitat distribution is currently only possible for limited areas of the seafloor, because maps of sediment distribution and bathymetry are not widely available. Comprehensive habitat mapping would benefit fisheries management by allowing thorough investigation into the relationships between fish and benthic habitats, especially for vulnerable life history stages such as juvenile settlement and spawning. It would also facilitate the management of fish habitat such as the designation and protection of areas that are particularly valuable for commercially exploited species.

Siting underwater construction projects

Maps of seafloor topography and sediment distribution are instrumental to engineers planning underwater construction projects. For example, the sediment distribution maps of Stellwagen Bank National Marine Sanctuary were used to site a fiber optic cable that passes through the Sanctuary. By referencing the sediment and shaded relief maps, engineers were able to avoid rock substrates and seafloor features when deciding the cable route, saving time and money and reducing the overall impact of the activity on the seafloor.

Several years ago, the sewage treatment system in the Boston metro area underwent a major overhaul in order to clean up Boston Harbor. The USGS conducted modeling of the currents and used sidescan-sonar to determine the sediment distribution in the proposed Massachusetts Bay outfall location. The maps and modeling data were referenced when deciding the final location of the new sewage outfall to insure that the conditions at the site were suited to disperse the outfall discharge.

Duke Energy recently installed a natural gas pipeline from Beverly to Weymouth including a connector into Boston Harbor. Seafloor habitat maps were not available for the project area, so they used sidescan-sonar to map the pipeline route to assess baseline conditions and attempt to avoid obstacles and minimize the amount of hard substrates disturbed to bury the pipeline.

Underwater archaeology

Shipwrecks and other important cultural resources are sometimes discovered as a result of acoustic seafloor surveys. For example, the swath acoustic survey on Stellwagen Bank National Marine Sanctuary identified numerous targets of interest to underwater archaeologists as potential shipwreck sites. In addition, they are also interested in subbottom profiling results to locate drowned river channels that may contain submerged prehistoric sites. The acoustic surveys that would be obtained as part of a Commonwealth-wide habitat mapping effort would allow underwater archaeologists to identify targets that may indicate the presence of shipwrecks or other submerged cultural resources that may require further investigation or protection.

2.2 Potential benefits of benthic habitat mapping

In addition to the case studies cited above, there are many other potential applications of benthic habitat mapping. Below are additional examples of the ways in which data from habitat maps could be utilized.

Marine protected areas

In many parts of the world, marine protected areas (MPAs) are increasingly being used to complement traditional management approaches to ensure sufficient protection of valuable species and habitats. MPA's typically restrict some types of potentially destructive activities from sensitive or unique habitat types. Referencing habitat maps to insure that all habitat types are represented within the MPA system would facilitate the design and siting of MPAs in Massachusetts. In addition, managers could compare the relative abundance of various habitat types and insure that areas with high conservation value (because they contain either rare habitat types, habitats that highly susceptible to degradation or habitat types that are known to harbor a large diversity of marine organisms or support rare species) are adequately represented within a MPA network.

Impact assessment of human activities on seafloor

Human impacts on the seafloor stem from fishing, mining, dredging, disposal, cable laying, construction of shipping and boating facilities, and energy related infrastructure (e.g. pipelines). The effects of fishing activities, especially bottom-tending gear have recently come under increased scrutiny. For example, the effects of trawling on marine habitats have been addressed by many researchers and have been the subject of a National Academy of Science Review (National Research Council 2003). Additionally, the effects of dredged material disposal on various types of seafloor environments have also been examined. However, the impacts of the myriad other human activities on the quality of marine habitats are relatively unknown. When comprehensive benthic habitat maps are available, researchers will be able to conduct focused studies on particular habitat types and will be able to inform managers of the individual and cumulative impacts of activities such as fishing, mining, dredging and dredge disposal on the seafloor. For example, researchers will be able to locate discrete areas of sandy and muddy seafloor and compare the impacts of pier construction on these two habitat types.

Design of monitoring and restoration programs

Habitat maps will aid in the design of water quality and benthic habitat monitoring programs by insuring that monitoring efforts are equally distributed among distinct habitat types and regions. Baseline habitat maps will allow managers and researchers to monitor changes in the spatial distribution and extent of various habitat types, particularly habitats that are indicators for general ecosystem health (e.g. seagrass beds).

As the awareness of the value of coastal habitat has increased in recent years, habitat restoration has become increasingly popular. Restoration occurs both on a proactive basis and as a mitigation tool. A synthesis of habitat restoration activities in the Gulf of Maine, indicated that restoration efforts are overwhelmingly focused in terrestrial or intertidal environments (Cornelison 1998). Benthic habitat maps would allow restoration planning to extend to subtidal habitats that are increasingly being affected by development activities such as watershed development, dredging, cable and pipe laying, etc.

Ecosystem modeling

Coastal and marine ecosystem modelers will benefit greatly from the spatially explicit information in benthic habitat maps, especially when the maps are combined with fisheries, existing use and other environmental data. In turn, improvements in marine ecosystem modeling will benefit resource managers and the general public because the uncertainty in ecosystem response to human and natural perturbations will be reduced. For example, the relationship between fisheries productivity and habitat type has only been characterized for selected species (e.g. scallops and gravel substrates). Benthic habitat maps would provide opportunities for quantitative assessment of the ecological function of other habitat types (e.g. mud bottom) for other commercially exploited species. This type of information can lead to habitat-based management, a first step towards ecosystem management.

Environmental risk assessment

The detailed bathymetry generated by a comprehensive mapping program would aid in environmental risk assessment for storm damage and sediment redistribution. In addition, the sediment distribution maps that would be produced as a result of state-wide benthic mapping would also aid in tracking the fate of pollution (in conjunction with studies of sediment transport and currents). Depositional areas presumably have slower currents and would be most susceptible to a buildup of sediment contaminants.

Benthic habitat maps would extend the triage utility of National Oceanic Atmospheric Administration's (NOAA) Environmental Sensitivity index maps to the subtidal zone. Some types of oil, especially thick unrefined products, are more likely to sink and environmental damage could be greatly reduced by referencing benthic habitat maps to determine where emergency clean up and restoration efforts should be directed. For example, after the September 2003 Buzzards Bay oil spill, response teams deployed booms in lobster traps to find areas of oil accumulation on the seafloor (Dave Janik, CZM pers. comm.). If they had benthic habitat maps, they would have been able to target their response efforts to sensitive habitats located in depositional areas.

Siting finfish aquaculture pens

Maps depicting the distribution of sediment types and various seafloor features (shaded relief) can also be used to site aquaculture facilities. A major concern for finfish aquaculture is the buildup of organic material (feces and unconsumed food) under net pens that can lead to dead zones on the seafloor. Sediment distribution maps can be used to insure aquaculture pens are not placed in depositional environments (mud or silty sediments) and shaded relief maps can be referenced to avoid topographic depressions, which could retain organic material.

Education and outreach

Comprehensive habitat mapping will also increase the public's awareness and concern for the marine environment. Benthic marine habitats are relatively inaccessible to the general public because specialized equipment such as SCUBA gear or submersibles are required to make direct observations. Maps of seafloor topography, surficial geology and benthic habitats will illustrate the diversity of features on the seafloor. By visualizing the distribution of various habitat types, members of the public may develop an enhanced sense of ownership of the marine resources that are managed on their behalf. This enhanced sense of ownership will lead to improved stewardship on an individual level and may lead to increased community-level action and planning.

2.3. Strong consensus from stakeholders regarding the need for maps

A recent National Academy of Science (NAS) report on the effects of commercial fishing (i.e. trawling and dredging) on seafloor habitat concluded that there is a great need for benthic habitat maps for marine resource management (National Research Council 2003). Several federal agencies, including NOAA and USGS, have commissioned a NAS study to specifically explore the need and interest in coastal mapping. The coastal mapping final report is forthcoming, but the study committee's preliminary findings indicated that the lack of marine habitat maps negatively affects stakeholders ranging from conservationists to managers to proponents of development projects (National Research Council 2004). All stakeholders interested in both protecting and utilizing ocean resources would benefit from marine habitat mapping because it would aid in siting projects and thus reduce the level of uncertainty and controversy concerning the impacts of a proposal.

2.4 Part of a larger effort in the region

The Massachusetts mapping strategic plan is part of several larger mapping initiatives in the region and in the nation. The Gulf of Maine Council sponsored a workshop to discuss marine habitat characterization and mapping in Sebasco, Maine in October, 2001. The consensus of the workshop was that habitat mapping was needed in order for managers and resource users to make informed resource-use decisions. Some of the Sebasco workshop attendees formed a working group that would later become the Gulf of Maine Mapping Initiative (GOMMI). GOMMI is a group of US and Canadian researchers and managers whose goal is to obtain habitat maps of the seafloor of the Gulf of Maine. The group has been endorsed by the Gulf of Maine Council and has published a strategic plan, which is available online: http://www.gulfofmaine.org/gommi.

The National Marine Sanctuary (NMS) System and USGS held a joint workshop at the University of New Hampshire in November 2002 to discuss the needs for habitat maps of the areas under NMS jurisdiction. The attendees agreed that information on the amount of various communities and habitat types is essential for effective management of Sanctuary resources. The habitat mapping that was conducted on Stellwagen Bank was regarded as a good example for the other sanctuaries. The NMS system is currently developing a plan to map (by acoustic or optical means) 100% of the seafloor in all of the Sanctuaries. The goal of both GOMMI and the NMS system is to improve the management of marine resources.

The Regional Association for Research in the Gulf of Maine also held a workshop focusing on marine habitat issues in 1994 at Boothbay Harbor, Maine. One of the conclusions was that the lack of accessible information about the distribution and extent of marine habitats inhibits both research and management in the region. The lack of information regarding the distribution of marine habitats was discussed at an Ocean Zoning Forum held in December 2002 in Boston, MA. Several ocean zoning goals were defined at the forum and it was generally acknowledged that zoning in the absence of accurate spatial information regarding the distribution of benthic habitats would not accomplish the goal of protecting sensitive areas.

Various other stakeholder groups have also expressed interest in marine habitat mapping. The New England Fishery Management Council is interested in marine habitat maps as a tool to improve fishery management. The Census of Marine Life is a private organization focused on assessing the biodiversity of the world's oceans. The Gulf of Maine has been chosen as one of their pilot areas and they have already compiled some prototype maps for the region. The ultimate goal of the Census is to implement ecosystem-based resource management, and they have also expressed strong interest in marine habitat mapping in the Gulf of Maine. It is their position that habitat maps are fundamental tools for ecosystem-based management. Finally, the Conservation Law Foundation and World Wildlife Fund Canada, are compiling various types of oceanographic, geologic and biological data in the Gulf of Maine. Their intention is to provide recommendations for siting marine protected areas to protect marine biodiversity. Spatially explicit benthic marine habitat information that would be generated from a statewide benthic habitat mapping program would benefit this effort and insure that their planning would encompass a diversity of habitats.

3. Considerations for habitat mapping

Definition of habitat

One of the most commonly used definitions of habitat is *a place where an organism lives* (Odum 1971). The theoretical underpinning of habitat is that organisms are distributed nonrandomly in space and their distributions are influenced by a combination of abiotic and biotic conditions (Fig. 3). The relative abundance of an organism between different habitat types is putatively related to the habitat quality; high quality habitats harbor high abundances (Auster et al. 2001). Some organisms have general physical requirements and can be found in various habitats, therefore both presence/absence and relative abundance data are important in delineating habitats.

In practice, habitat is a difficult concept to encapsulate because a multitude of factors influence the type and quality of habitat that a particular area provides.

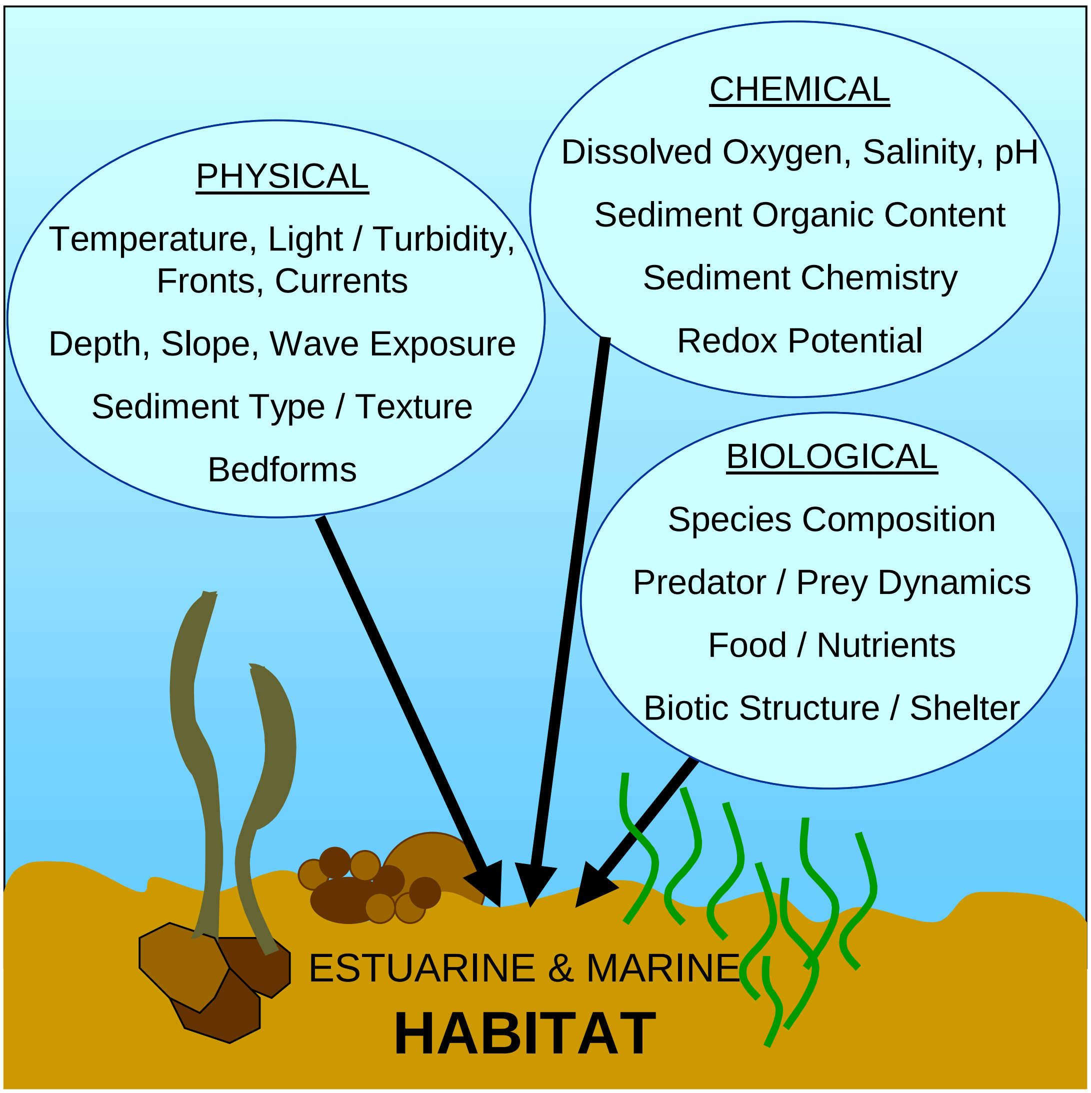

Figure 3. Schematic depicting the various physical, chemical and biological factors that affect the type and quality of marine habitat that a particular area affords.

Habitat mapping

The term benthic habitat mapping (or seafloor habitat mapping) has different connotations for various groups. For this strategic plan, benthic habitat mapping will be accomplished by characterizing the most tractable attributes of the marine environment, especially the physical and biological structure of the seafloor. By characterizing the important physical (depth, surficial geology, slope) and biological (vegetation and fauna) factors that influence the type and quality of benthic habitat, maps that show the distribution of various types of benthic habitats can be created. Although a comprehensive list of all the potential benthic habitat classes that may be encountered in a statewide survey is not appropriate here, some examples of benthic habitat types that may be depicted on maps include: submerged rooted vegetation (seagrass), mud flats, sand plains, cobble and boulder fields and mixed hard substrates.

Habitat mapping is a form of geographic modeling, it is based on the premise that the occurrences of community types can be predicted by analyzing important environmental factors. Biological sampling for habitat maps must take place at discrete points or small sections of the seafloor while acoustic or optical equipment can provide swath coverage of the seafloor. When the associations of various communities with environmental factors (temperature, sediment texture, topography, depth, salinity, etc.) are well documented, habitat mapping can proceed by surveying the important environmental factors and then extrapolating the correlation of various habitat types with these factors. Even when the relationships between biological communities and environmental factors are well documented, biological sampling to groundtruth acoustic data is necessary (more on groundtruthing in section 4.3).

For benthic marine organisms, water depth and surficial geology (substrate grain size and seafloor roughness) strongly influence the species composition of a particular area. Multibeam echosounders obtain data on both of these factors simultaneously and have become the favored mapping technique for water >10 m deep. The benthic habitat mapping initiative in Massachusetts will have a two phase approach. The first phase will involve mapping surficial geology (via data collected by acoustic or spectral sensors) and the second phase will integrate biological data (gathered via groundtruth sampling) into the surficial geology maps to produce benthic habitat maps (for details refer to section 11). The preliminary basis for interpretation of habitat polygons for this statewide plan will be based on surficial geology and depth, but available information on currents, salinity, and temperature will also be evaluated and incorporated as appropriate.

Habitat classification systems

One of the biggest obstacles to conducting large-scale benthic habitat mapping may be the lack of a commonly accepted marine habitat classification system. The National Research Council's report on the effects of trawling and dredging on seafloor habitat recommended adoption of a national habitat classification system (National Research Council 2003). Several marine habitat classification schemes have been proposed and used by various researchers, but none are universally accepted because each has unique drawbacks. The most widely used habitat classification system developed by Cowardin et al. (1979), does not adequately address subtidal marine habitats. Other schemes are only appropriate for use with particular technologies. For example, Rhodes and Germano (1982) developed a habitat classification scheme for use with sediment profile imagery. However, this classification system does not include hard bottoms because the camera does not penetrate the seafloor in rocky substrates. One recommendation of this strategic plan is that all raw data be stored, even upon completion of a habitat map, in order to apply a different habitat classification system if needed at a later date.

The need for a universally accepted marine habitat classification system is also being addressed by the International Council for Exploration of the Seas (ICES) working group on habitat mapping. The European Union Nature Identification System is being tested by various mapping projects, and recommendations for its universal application are being developed by the ICES habitat mapping working group. Allee et al. (2000) proposed an estuarine and marine classification system that was based on the recommendations of a team of experts; this system is being tested and refined. In addition, the NOAA's Coastal Services Center has contracted NatureServ, an environmental consulting firm, to develop standards for a marine habitat classification system. One important aspect of a habitat classification system should be the incorporation of the temporal scale over which variables change. In a hierarchical classification system, variables that could change over relatively short time periods (such as the presence of feeding voids or vegetation) should be incorporated at higher levels in the classification than variables that are unlikely to change (such as hard substrates) (Kvitek et al. 1999).

The lack of a universally accepted marine habitat classification system strengthens the need to insure that standardized methods are used to make the maps. The methods to draw the various habitat polygons on the maps must be defensible and repeatable regardless of who analyzes the data. The use of multivariate and spatial statistics to create the habitat map will insure that the creation of the various habitat polygons will be minimally subjective and repeatable (for details see section 114). These methodologies will contribute to the transferability of the methods between biogeographic regions and will provide a defensible definition of habitat types.

<u>Audience</u>

One of the most important considerations when undertaking any mapping project is the intended use of the map. A variety of stakeholders will benefit from the comprehensive mapping of the Massachusetts marine waters including those concerned with: underwater archaeology, cable/pipe laying, navigation/shipping, sand/gravel mining, offshore energy development, aquaculture, resource management, modeling storm impacts, fishing and research. For this strategic plan, the primary audience will be fisheries and marine resource managers and the resolution of the maps must be detailed enough to meet their needs such as guiding resource assessment surveys and facilitating planning.

<u>Mapping data standards</u>

The technological innovations in acoustic and optical equipment that have facilitated mapping for large areas of the seafloor have led to several large benthic mapping projects in the US, Canada and Europe. In an effort to coordinate and standardize the various habitat mapping efforts, the ICES Working Group on Marine Habitat Mapping is developing a source document that lists considerations and recommended data standards for marine habitat mapping. The document is being assembled by a variety of scientists and managers, and it may take several years to complete. The Massachusetts Office of Coastal Zone Management (CZM) is tracking the working group progress and as general consensus is reached regarding standards, they will be examined and addressed for on-going and future habitat mapping projects in the Commonwealth.

Some of the important considerations for data acquisition and management are listed in the GOMMI strategic plan (Todd et al. 2004).

4. Mapping technologies

There are four steps required to make a benthic habitat map: data acquisition, processing, interpretation of data and distribution of the results. A general overview of the equipment that can be used for benthic habitat data acquisition is given below to provide a comparison of the types of data that each obtains. The other steps for map making are explained in later sections.

There is a large variety of equipment used to obtain data needed for benthic habitat mapping. The types of equipment most suited for a particular area depend on the water depth and the types of data to be gathered. For example, acoustic or optical equipment is used to obtain bathymetry and geological data, while biological data is usually obtained via direct physical sampling methods such as core or grab samples or through video or still photographs. The various types of equipment vary in their data acquisition methods, in their resolution, and in their relative strengths and weaknesses. For further information regarding advantages and disadvantages of each type of equipment, Davies (2001) has a table in chapter 5 that compares resolution, cost, efficiency, logistical requirements, etc. Similarly, Kenny et al. (2003) presented a table comparing the effort versus resolution for various remote sensing technologies.

4.1 Remotely sensed data

The advantage of remotely sensed data is that large areas of the coast can be surveyed quickly. The disadvantage of remotely sensed data is that the resolution is usually lower compared to data collected by more direct means. Each type of remote sensing instrument is also subject to discrete disadvantages. For example, data gathered via aerial methods will have much coarser resolution than data gathered by a SCUBA diver. Additionally, imaging of the ocean via aircraft or satellites requires clear, shallow water; clouds can also obscure the view. Acoustic data quality can be diminished by propeller wake, wind (increased sea state) or by changes in water temperature, salinity or pressure. In all cases, remotely sensed data requires some degree of verification, or groundtruthing, which is described in section 4.3.

<u>Remote sensing from the air</u>

Satellite Sensors

A variety of satellite sensors have been developed to detect environmental conditions in the oceans. The information derived from satellite sensors can be used to assess conditions such as sea surface temperature and color. The Advanced Very High Resolution Radiometer (AVHRR) measures ocean surface temperature in cloud-free areas and can be used to detect upwelling which strongly influences the productivity of an area. The Sea-viewing Wide Field of View sensor (SeaWIFS) provides ocean color information which can be used to estimate phytoplankton biomass and to track sediment transport patterns. Satellite data are generally available free of charge; several websites offer compilations of satellite images (e.g. http://www.oeatech.com/eos.htm, http://landsat7.usgs.gov/index.php). The disadvantages of satellite technologies are that the data are often low-resolution; they are useful for detecting broad scale patterns (e.g. presence of blooms in the Gulf of Maine) but not for site-specific characterization. In addition, because clouds can obscure satellite sensors, one cannot always rely on having access to satellite-derived data for a particular location.

Hyperspectral Sensors

Hyperspectral imaging instruments collect spectral reflectance data in shallow water or over land. Various types of substrates (sand, mud, rock) or vegetation (algae, seagrass) have different spectral properties, and this information can be used to infer habitat types. Hyperspectral sensors are mounted on small aircraft and detect reflectance in up to 288 narrowband wavelengths in the visible and infrared spectrum. The user can specify which spectral bands are measured and the bandwidths (i.e., range of wavelengths) used. Geographic Positioning System (GPS) coordinates and altitude are recorded along with the reflectance data. The data produced by hyperspectral imaging are very high resolution, but must be processed using special software before they can be imported into Geographic Information Systems (GIS). Like all aircraft-mounted technologies, hyperspectral sensors require clear, calm, shallow water to obtain high quality data. Variable water chemistry, tidal or solar conditions can alter the spectral signal of particular bottom features, and therefore a highly trained observer is required to interpret the data.

The Compact Airborne Spectrographic Imager (CASI) was the first commercially available hyperspectral sensor. The information gathered by CASI systems can be used for mapping bathymetry (depth) and habitat (substrate and vegetation) in clear, shallow water. CASI can also be used to assess some water quality parameters such as the presence of algae that are associated with harmful algal blooms (e.g. red tides) or for detecting oil slicks. CASI is generally only effective within secchi disk depths (Precision Identification, 2002) but is more cost effective than swath acoustic techniques, especially in shallow water due to its ability to cover a larger area in less time. It costs approximately \$3100-\$3900/ km^2 for CASI data acquisition and processing (Kvitek et al. 1999). CASI is capable of obtaining meter resolution data, making this technology ideal for nearshore subtidal habitat mapping in areas with high water clarity.

CASI has been used to map the extent of the invasive algal species, *Codium fragile* in Nova Scotia, and *Caulerpa taxifolia* in the Mediterranean (Ripley et al. 2002). Larsen and Erickson (1998) used it to delineate various types of intertidal habitat in Maine. They found that it was very successful for differentiating several types of intertidal algae, and that it also was suitable for differentiating different types of substrates.

Light Detection and Ranging (LIDAR)

The primary function of LIDAR is to measure the distance between the ground and an aircraft using a laser. LIDAR sends a short laser pulse and the elapsed time for the signal to be reflected from the ground and returned to a receiver is recorded. The nature and strength of the return signal provide additional information about the bottom type of the target. The laser's wavelength is optimized for the particular environment where the survey is to be conducted (e.g., infrared for terrestrial surveys and blue/green wavelengths for bathymetric surveys). Under ideal conditions, blue/green wavelengths from LIDAR lasers can penetrate up to 60 m of water (Kvitek et al. 1999), but generally its penetration is 2-3 times the Secchi disk depth. The swath width of LIDAR varies with the distance between the aircraft and the ground, but it is independent of water depth.

The Army Corps of Engineers' Scanning Hydrographic Operational Airborne LIDAR Survey (SHOALS) collects both topographic and bathymetric data. Highly accurate subtidal bathymetric maps (up to 20 cm vertical resolution) can be generated using LIDAR in sandy areas, but this technology is not as effective in rocky habitats. LIDAR data are also difficult to classify in areas with low topographic relief and the laser does not penetrate dense vegetation. LIDAR will not penetrate clouds, so missions must be timed to occur on cloudless days or days with a high ceiling.

LIDAR is a relatively high cost technology (approximately $3100-$3900/ km^2, Kvitek et al. 1999), but it is cost effective in shallow water when compared to the narrow swath width of multibeam sonar. LIDAR has been used to detect high concentrations of chlorophyll in Delaware Bay and it can also be used for airborne fisheries surveys, although this application of the technology is still under development. LIDAR can be used simultaneously with CASI, and these two technologies are often used in combination.

Aerial photography

Aerial photography can provide some information about the seafloor in the subtidal zone (substrate color, presence/absence of submerged vegetation) and is primarily used for delineation of different habitats in the intertidal and shallow subtidal zone. Aerial photography has been successfully used to map benthic habitats in water up to 10 m depth. Airplanes flying at relatively low altitudes are usually employed to obtain aerial photography and images are recorded on either film or digital equipment. Positional information of the aircraft is generally recorded concurrently using both a GPS and an Inertial Motion Unit (IMU). Digital images have the advantage that they can be viewed in the field, allowing immediate verification of the image quality. Disadvantages of aerial photography are that the timing of flights must coincide with low tide, good weather, and calm, relatively clear water. Aerial photography is generally useful for mapping habitat types that differ in color (e.g. for detecting the presence/absence of vegetation when the vegetation color differs from that of the substrate). Aerial photography is not as useful for detecting differences in substrate types (e.g. rock versus mud) when they have similar colors. Aerial photography has been used by the DEP to map seagrass beds throughout the Commonwealth (see description in section 6.1). Aerial photography has also been used to document the numbers of organisms on the surface of the water, such as the surveys of Atlantic Bluefin Tuna carried out by the New England Aquarium and of seabirds' use of Nantucket Shoals carried out by Massachusetts Audubon. Habitat types in the intertidal zone have also been delineated by DEP from color infrared orthophotographs (see description in section 6.3).

Remote sensing underwater

Remote sensing underwater can be accomplished using either acoustic or optical instruments. There are a variety of sensors that utilize acoustics to infer bathymetry and/or substrate characteristics. Electro-optical instruments, such as lasers, are used to create high-resolution images of the seafloor. Most underwater remote-sensing equipment use differential GPS or higher resolution navigation systems to insure high positional accuracy.

Acoustic instruments emit sound waves and record the signal's return time (in addition to other characteristics) to derive seabed information. Some of the other characteristics of the return signal analyzed include: angle, amplitude and phase. Many factors influence the nature of the return wave, including but not limited to: sediment physical and geotechnical properties, the slope and rugosity (roughness) of the bottom, the abundance of benthic organisms (only with high frequency systems), and the presence of pycnoclines and thermoclines in the water column. Different types of substrate influence the acoustic reflectivity, or backscatter, of the return wave.

The various acoustic sensors differ in: the frequencies of sound produced and the design of the sound emitting and receiving device (transducer). The frequency of the transmitted acoustic pulse affects resolution, range and ability to penetrate the seafloor. High frequency systems yield higher resolution data (ability to resolve seafloor features) but achieve less range (distance covered on either side of the senor). Lower frequency systems achieve greater ranges, but yield lower resolution data. Acoustic systems designed to penetrate the seafloor (seismic-reflection subbottom profilers) emit lower frequency acoustic pulses than surficial mapping systems such as multibeam echosounders and sidescan-sonars. The lower frequency enables these seismic systems to provide a cross-section of the structure and layering of sediments, ultimately mapping the underlying geologic structure of the seafloor. Subbottom information is especially useful for identifying areas of sediment deposition or erosion.

Single-Beam Acoustics

Single-beam echosounders are typically mounted directly on a vessel's hull. The transducer emits an acoustic pulse and then "listens" for the return signal. The time for the signal to return is recorded and converted to a depth measurement by calculating the speed of sound in water. Single-beam echosounders generate point depth data directly beneath the instrument; therefore surveys conducted with single-beam echosounders leave gaps in coverage. The area covered by the acoustic pulse is typically circular and the diameter of seafloor covered by the emitted sound is dependent on water depth. The emitted sound travels through the water column forming a cone-like coverage, with the footprint (diameter) of sound increasing with the distance from the sensor to the seafloor. The distance between sample points is dependent on vessel speed and water depth with more distance between points at higher speed and deeper water. Interpolation is required to fill in the gaps between data points. Along with depth finding capabilities, single-beam echosounders can also be used to locate schools of fish in the water column.

Signal processing systems analyze characteristics of the return wave of the echosounder's acoustic pulse, allowing inferences to be made about seafloor sediment characteristics. The RoxAnn sensor (Marine Microsystems Ltd.) is a signal-processing unit that is used by ecologists to characterize habitats in shallow waters (1.4 – 30 m). RoxAnn records depth, time, geographic location and bottom characteristics approximately every second. The first (bottom return) and second (multiple) returns are analyzed by RoxAnn to yield bottom roughness and hardness, respectively. By examining the information from both returns, sediment type can be inferred as long as calibration protocols are closely followed. RoxAnn works effectively at vessel speeds of 2.5-10 knots. The area of bottom characterized by the sensor is generally one- tenth the water depth (similar to single-beam echosounders, RoxAnn acquires data directly beneath the sensor). RoxAnn is not effective in very shallow water (less than 1.4 m) and the narrow coverage may not be suitable for interpolation in areas with high variability in sediment distribution.

CZM and DEP ecologists use RoxAnn to map shallow water habitats, particularly seagrass beds. For example, RoxAnn was used to delineate the deepwater edge of seagrass beds in Salem Sound in fall 2002 to compare with the results obtained from aerial photograph delineation.

QTC VIEW™ (Quester Tangent Corporation) is another commonly used signal-processing instrument that produces seabed classification from a single-beam sonar instrument. It has been used to make benthic habitat maps off the western coast of Portugal (Freitas et al. 2003).

Multibeam Sonar

Multibeam sonar functions on the same principle as single-beam units but because multibeam sonar simultaneously emits many acoustic pulses, obtaining continuous swaths of coverage rather than a single point beneath the vessel. Up to 127 acoustic beams arrayed in a fan-like shape are emitted from the transducer. Because multibeam sonars acquire a continuous swath of data, large areas of the seafloor can be mapped with 100% coverage, thus there is no need for interpolation between survey tracklines. The major output product of multibeam sonar units is bathymetry data, but the backscatter strength can also be used to infer textural properties of the seafloor surficial substrate (sediment grain size, roughness, etc.). A strong return denotes the presence of bedrock or coarse sediment such as gravel. Weak backscatter is indicative of soft sediments such as fine-grained sand or mud.

The receive and transmit cycle of multibeam sonar can be characterized as a directed cone of sound that is emitted and received within a fixed angle. As water depth decreases, a narrower portion of cone will intersect the seafloor, which results in a smaller portion of the seafloor being ensonified (imaged) with decreasing water depth. Generally, the width of the swath is five times greater than the water depth in waters <30 m, but this ratio generally increases in water >30 m deep. Multibeam sonar surveys are costly in shallow water because of the reduced swath width. Multibeam sonar equipment are available in a range of acoustic frequencies (12- 500 kHz) and system configurations (which affect survey speed). The objective of the survey and the study area influence the type of multibeam sonar that is most suitable for the particular survey.

Multibeam sonars are generally attached to the bottom of a ship's hull or on a stable side-mount. Inertial motion units are usually incorporated into multibeam sonar systems because they allow researchers to compensate for the vessel's movement (pitch, roll, etc.) when interpreting the bathymetric data. These data, along with measurements of tidal stage and the speed of sound within the water column, are necessary to accurately map bathymetry.

The area that the swath covers (the footprint) increases with distance of the sensor from the seafloor. The more the acoustic beams are spread out before they hit an object, the lower the spatial resolution of the data. Therefore, in order to create accurate maps in very deep water, sonar devices are towed on long cables or mounted on an autonomous underwater vehicle (AUV) at a depth suitable to collect data at the desired resolution. Passing through large volumes of water also decreases the energy of the sound wave, so low frequency sound waves are used when mapping in deep water. The longer wavelength of low frequency sound waves allows them to travel further in deep water without having much of the signal strength absorbed.

Multibeam sensors allow 3D visualization of topography of seafloor because of their high horizontal (10% of water depth) and vertical (1%) resolution (Valentine et al. 2003). The bathymetry and backscatter datasets are co-registered (acquired with the same system) and therefore they can be layered on top of each other to visualize how seafloor morphology is related to the surficial substrate characteristics. This surficial geology map allows the users to visualize the relationships between seabed forms, depth and sediment distribution. USGS used multibeam sonar to map Stellwagen Bank and western Massachusetts Bay (see: http://pubs.usgs.gov/fs/fs78-98/, description in section 6.1) and they recently used it to map nearshore areas of the North Shore of Massachusetts (Section 1, Figure 8.1).

Interferometric Sonar

Interferometric sonar is similar to multibeam sonar in that it measures the strength and timing of returned acoustic pulses to simultaneously collect bathymetry and backscatter data, but the design of interferometric sonar is more similar to sidescan-sonar (see below). The difference between interferometric and multibeam sonar are that multibeam sonar measures the return time of an acoustic pulse through a series of fixed angles, while interferometric sonar measures the angle of sound returning within a given return time. Because the system is not limited to fixed angles, as with multibeam, interferometric sonar can achieve wider swath width in shallow water than multibeam. Interferometric sonar swath width in water depths <30 m is generally 8-10 times the water depth. In contrast, a 100kHz multibeam would only achieve swath widths of 3-5 times the water depth under similar conditions.

Interferometric sonars are generally either hull mounted or mounted off the side of vessel in a stable side mount. Similar to multibeam sonar, the attitude of the vessel, the tidal stage and the speed of sound in the water column must be incorporated into the bathymetry calculations for accuracy. The USGS used interferometric sonar in conjunction with sidescan sonar and seismic reflection profiling to map surficial geology of the South Essex Ocean Sanctuary in fall 2003 (see description in section 10).

Sidescan-Sonar

Sidescan-sonar systems generate high-resolution backscatter of seafloor roughness for interpretation of surficial sediment types. Naturally occurring bedforms such as sand waves and scour marks can be visualized with sidescan-sonar in addition to anthropogenic disturbances such as anchor, dredge and trawl scars. This is possible because of the low grazing angle with which the sound waves hit the seafloor; the resulting acoustic shadows are useful for identifying seafloor features.

Sidescan-sonar equipment is available in a range of acoustic frequencies, the optimal equipment is determined by the objective of the survey. Unlike multibeam sonar, the swath width of the sidescan-sonar is not dependent on water depth, therefore this type of equipment is most suited for mapping in shallow water. Sidescan-sonar is towed behind the survey vessel in a unit known as a towfish. The optimal height at which to deploy the towfish depends on the water depth. One disadvantage of sidescan sonar is that a vessel's speed generally cannot exceed 7 knots while it is being towed and it does not ensonify the seafloor directly beneath the towfish. It is also important for the vessel to be moving in a straight line when collecting sidescan-sonar data in order to avoid distortion of the beams as the vessel turns.

Aside from its utility for seafloor mapping, sidescan-sonar is also used to locate pipeline routes and shipwrecks, to assess potential hazards to navigation, for geological investigations and for military uses. Brown et al. (2001) found that seabed morphology exerted strong influence over community structure, and found sidescan-sonar output useful for visualizing bedforms. Existing sidescan-sonar backscatter obtained by NOAA's Office of the Coast Survey in Boston Harbor is being processed into a surficial geology map (see description in section 8). Sidescan-sonar was also used to survey the Buzzards Bay, MA dredged material disposal site, but the backscatter from this small area has not been processed and interpreted to map the surficial sediment distribution.

NOAA's Office of the Coast Survey often uses a combination of multibeam and sidescan-sonar for making navigational charts. If they are not running a complete multibeam sonar survey, they will use the sidescan sonar to identify seafloor features. When the sidescan sonar indicates the presence of a 'target' (presumed shallow-water object), they will survey the selected area with multibeam sonar.

Seismic Reflection Profiling (Sub-bottom Profiler)

In order to accurately map surficial geology, sub-surface geological data is needed to complement the morphology and sediment distribution data obtained by bathymetric and sidescan-sonar systems. Sub-bottom profilers take advantage of the acoustic impedance (speed of sound traveling through a medium multiplied by the density of the medium) properties of different substrate types to obtain cross sectional data of the seafloor's subsurface. As an acoustic pulse hits a change in impedance, some energy is reflected back to the receiver. The impedance contrasts between different mediums yields the seismic signature. Seismic reflection profiling equipment generates low frequency acoustic waves in regular intervals that penetrate the seafloor and the various stratigraphic layers. A hydrophone (underwater sound receiving device) or series of hydrophones receive the acoustic signals in analog form. The analog signal from the hydrophone is displayed as a profile of seabed structure. Measurements of the boundaries between substrates indicate the relative thickness of the various stratigraphic layers. The seismic reflection profiles obtained along the ship's track are interpolated to define the underlying seafloor structure.

Seismic profiling systems are available in a variety of acoustic frequencies. The depth of penetration of the acoustic signal into seafloor sediments is dependent on the frequency used and the sediment or substrate type. A typical sub-bottom profiler penetration is 80 to 100 m depth, thus allowing the identification of potential hazards such as faults or areas of gas migration. Chirp systems (approximately 2 to 20 kHz) emit a narrow band of wavelengths that obtain high-resolution sub-bottom data. When coarse substrates occur at the surface, their high reflectivity decreases the ability of sub-bottom profilers to resolve distinct layers (Limpenny and Meadows 2002). Additionally, high concentrations of organic compounds on the seafloor can also impede the penetration of the acoustic signal. In these cases, the utility of the sub-bottom profiler for interpreting underlying seabed structure may be limited, nevertheless, the lack of penetration provides valuable information about the structure of the shallow seabed.

Laser Line Scan

Laser line scan is an electro-optic imaging technique used to produce high-resolution images of the seafloor. Laser line scan operates by scanning blue-green laser in a 70° arc over the seafloor, illuminating it in narrow strips. The instrument measures the magnitude of the reflected light. The results from each scan are combined to create an image that approximates the quality of a conventional photograph. The resolution of laser line scan ranges from mm to cm, and the range is two to five times larger than that of conventional photographic equipment. Laser line scanning instruments are generally towed and therefore the area covered will vary with the height of the tow vehicle above the seafloor. Laser line scans are less affected by backscatter from suspended sediment than other technologies that require underwater lights, but they are still negatively impacted by poor water visibility. Laser line scan survey speeds can range from 1 to 6 knots (Precision Identification 2002). The advantage of the laser line scan is that it generally provides enough resolution to identify organisms (acoustic techniques lack this resolution) and has a swath width that greatly exceeds that of conventional photography or video.

The utility of laser line scan has been assessed for the identification and characterization of essential fish habitats in Big Creek Ecological Reserve off the central California coast (see:

http://www.nurp.noaa.gov/Spotlight%20Articles/laser.html). The study area had previously been surveyed with sidescan-sonar and video. Project scientists found that they could visualize the spatial relationships between organisms and the physical habitat features (sediment texture, topography) with laser line scan.

Videography or Photography

Underwater video and photography are simple yet effective technologies for obtaining data related to marine habitat type. Underwater images can be collected via SCUBA, remotely operated vehicles, frame mounted cameras or by dropping a camera over the side of a boat. Image analysis software is used to analyze the coverage of various vegetation or sediment types in photographs or individual video frames. In addition, the density of epibenthic (seafloor surface dwelling organisms) species can be calculated, providing further information regarding the quality of a particular habitat. As previously mentioned, Brown et al. (2001) found seabed morphology appeared to exert a strong influence over community structure. Video transects can be a valuable tool to examine the relationship between seabed morphology and community structure. Like other visual techniques, the quality of video or photographic data is negatively affected by turbid water, which can limit their applicability in certain areas.

Sediment Profiling Imagery

A sediment profile system uses a camera and a wedge-shaped prism to penetrate and photograph the sediment/water interface (Rhoads and Germano 1982). Weights drive the prism into the sediment and oil-filled pistons control the rate of descent. The prism is filled with distilled water to prevent hydrostatic pressure from distorting the plexiglass faceplate. Turbidity does not interfere with the image quality because the plexiglass is directly in contact with the sediment. A mirror on the back of the prism reflects the sediment profile up to a camera that is mounted above the prism. The prism penetrates up to 20 cm of sediment. The resulting image has resolution on the order of mm.

Figure 4: A sediment profile image taken in soft sediments. The depth of penetration of the camera indicates the compaction and hardness of seafloor sediments. Sediment grain size can be estimated from the photograph as well the depth of oxygenation of the sediments. The camera’s penetration into the seafloor allows visualization of some benthic infauna (organisms that live entirely within seafloor sediments). The types of organisms present, and their feeding modes, can be used to infer the successional stage of the community. Sediment profile imagery is not effective in hard or tightly compacted sediments.

Sediment profile systems provide a large amount of data about the sediment/water interface. Because the prism slices through the sediment, a measure of habitat complexity can be obtained. The relative proportion of organisms with different feeding modes (e.g. surface feeders vs. deep burrowing deposit feeders) indicates the successional stage of the community which is an indication of the condition of the habitat (Rhoads and Germano 1986). The depth of the apparent redox layer (depth at which the sediment becomes anoxic) and sediment grain size estimates can also be made using the profile imaging system. One disadvantage of the sediment profile system is that it does not work in rocky bottom areas. Like other point sampling techniques, many samples are required to characterize habitats with a sediment profile imagery system, especially in areas of high spatial variability. However, when combined with other technology such as multibeam sonar, detailed analyses of benthic habitat can be conducted. CZM used sediment profile imagery to characterize the benthic habitats in Gloucester Harbor, Salem Harbor, New Bedford/Fairhaven, Fall River, Buzzards Bay and Boston Harbor. The results of the sediment profile imagery were used in the selection of appropriate sites for dredged material disposal.

4.2 Direct physical sampling

Direct physical sampling of the seafloor allows researchers to obtain highly detailed data on sediment characteristics and resident organisms. Unlike remotely sensed data, direct physical sampling only cover a very small spatial extent with each sample or transect (Table 1). Often broad-scale habitat mapping programs utilize remote sensing technology to gain a general understanding of the distribution of sediment types. Target areas are then identified for higher-resolution surveys using direct sampling techniques.

Table 1: Summary of mapping technologies and their corresponding scale of inference (adapted from Kvitek et al. 1999)

Scale	Mapping Technology
1:5,000-20,000	LIDAR, aerial photo, CASI
1:1,000-10,000	Acoustic methods (multibeam, sidescan-sonar)
1:10-10,000	Laser line scan
1:10-1000	SCUBA or ROV transect
1:10-100	SCUBA quadrat, Grab, core samples, photography

Grab or Core samples

Grab and core samples are used to obtain information about benthic organisms (epi- and infauna) and to groundtruth sediment texture observations made using remote sensing data. Grab or core sampling is generally most effective in soft sediment environments, but some grab samplers have been designed specifically for sampling coarse substrates. Brown et al. (2002) provide a table that compares the various types of grab samplers, the area of surface sampled and their relative advantages and disadvantages of each type of equipment. Depending on the design of the sampler, both core and grab samplers can preserve stratification in the sediment so the depth of the redox layer (depth at which the sediment becomes anoxic) can be calculated.

Generally, core samplers penetrate deeper into the sediment, while grab samplers cover a wider area. Processing core or grab samples is time intensive but these samples yield highly detailed information. Some examples of the type of information that can be obtained include the density and species identity of infauna and the amount of organic content in the sample. If grab samples are obtained in an area of mixed substrates (e.g. cobble and fine sand), the cobble can prevent the sampler from closing and the soft sediments will be lost. Therefore it is best if a bottom photograph can provide a preview of the seafloor to determine what type of sampling gear is most suited to the environmental conditions.

Gravity corers are also used to obtain sediment samples. Hydraulic pistons control the rate at which the corer penetrates the sediment so that disturbance is minimized. The gravity corer is able to penetrate about 70 cm in muddy sediments.

SeaBOSS

The USGS has combined a variety of instruments used for groundtruthing into one unit, SeaBOSS (SeaBed Observation and Sampling System) (see http://pubs.usgs.gov/fs/fs142-00/fs142-00.pdf). This instrument is used to accomplish groundtruthing of remotely sensed data obtained by acoustic sensors or seismic profiling. SeaBOSS has two video cameras, one still camera, a depth finder and a Van Veen grab sampler. Laser points, spaced 20 cm apart, appear in SeaBOSS's photographic frame, thus providing scale for the view frame and allowing density calculations to be made. The shape of the Van Veen sampler resembles a clam shell and it obtains sediment from a 0.1 m^2 area to about 20 cm depth, depending on the substrate. The SeaBOSS unit is compact enough to be deployed from either small or large vessels and SeaBOSS has been used to obtain groundtruth samples of Stellwagen Bank.

Suction sampling

The Acadian province (north of Cape Cod) has a particularly high concentration of seafloor substrates that are gravel, cobble or even solid rock outcrops; hard substrate is also found less frequently in southern Massachusetts waters (Virginian province). These hard substrates pose a challenge for obtaining quantitative data on species abundance. While photographs are effective for documenting the abundance of algae and some epifauna in rocky substrates, other organisms that live on the undersides of rocks or in the interstitial spaces, are not effectively sampled using photographic techniques. Suction sampling is necessary to quantitatively sample hard substrates and can be accomplished by divers or by remotely operated equipment. While suction sampling is primarily used to sample hard substrate, soft sediments (sand and mud) can also be sampled by suction sampling.

Divers can operate an airlift suction sampling device that is created by attaching an air hose to a scuba tank and attaching tubing with a collection bag at the end (for details on see Coyer and Witman 1990). The air hose and tube create a vacuum that sucks sediments and organisms into the collection bag. In order to insure that the area sampled is consistent between locations, a steel quadrat with high sides is placed on the bottom and the contents are vacuumed up by the airlift. Divers need to be careful to insure that they "vacuum" between the rocks that are too large to be sucked into the bag. For deeper water, remotely operated suction sampling devices must be employed. These are usually deployed from autonomous or remotely operated vehicles. Like the core and grab samples, processing suction samples is a time consuming process, nevertheless, detailed information on the density, biomass and relative abundance of organisms can be obtained from suction samples. For example, the Division of Marine Fisheries (DMF) uses suction sampling to monitor the abundance of lobsters in the early benthic phase.

Trawls

Trawls have traditionally been used to assess the abundance of commercially valuable fish species, and small mesh sizes can be used to retain a higher proportion of the nekton community (fishes, squids, decapod crustaceans) and have been used for research purposes. One of the most commonly used trawls is the otter trawl, which has two heavy doors that drag along the seabed and sweep benthic organisms into the netting. Beam trawls are similar to otter trawls but employ steel beams to scrape the seafloor. Trawls can be used to obtain semi-quantitative samples by insuring that the trawl is deployed for a specified amount of time and that the vessel is moving at the same speed during all trawls. As mentioned in section 2.1, Auster et al. (2001) found a correlation between the distribution of some sediment types in Stellwagen Bank National Marine Sanctuary and the species composition and abundance of some fish species obtained in trawls. This research demonstrated the utility of trawl data (in combination with acoustic survey and other groundtruthing methods) for assessing the type and quality of benthic habitats.

4.3 Groundtruthing

All remote sensing technologies require groundtruthing to accurately interpret the data. Bathymetry derived from interferometric sidescan or multibeam sonar sensors is often checked with single beam echosounders. Groundtruthing biological and geological data is usually accomplished by taking bottom grab samples, photographs or obtaining seismic profile imagery (as described in section 4.2). The accuracy of the interpretation will improve with the amount of groundtruthing that is conducted; therefore extensive groundtruth sampling programs utilizing a variety of methods will result in the highest quality map products. Scientists at USGS Coastal and Marine Geology Program have found that the nearshore surficial geology in the Gulf of Maine is sufficiently complex to necessitate the use of several different types of remote sensing technologies in order to produce accurate maps. They use a combination of sidescan-sonar, multibeam sonar and seismic reflection profiling to generate maps that depict bathymetry and sediment type distribution. They have found that by incorporating swath bathymetry with sediment distribution data, they were able to re-interpret geologic features of the inner continental shelf. To verify acoustic data and characterize habitats, USGS scientists also obtain photographic images and grab samples using the SeaBOSS system.

5. Nearshore mapping protocols and considerations

In 1995, NOAA developed a protocol for conducting nearshore benthic habitat mapping through two workshops. The Coastal Change Analysis Program (C-CAP) (website: http://www.csc.noaa.gov/crs/lca/ccap_program.html) focuses on the use of remote sensing technologies, especially aerial photography or satellites to detect coastal habitat change. The protocol was written so that comparable data would be collected in various regions, thus facilitating comparisons between different datasets (*NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation, NMFS Technical Report 123).* The Massachusetts DEP follows C-CAP protocols to obtain aerial photography for the delineation of seagrass beds throughout the Commonwealth (see description below).

Seafloor mapping employing multibeam acoustic technologies is a rapidly expanding research area (Todd et al. 2000; Kostylev et al. 2001; Green et al. 2002). However, as previously mentioned, swath acoustic surveys are generally only cost effective in deep water (>30 m). There is increasing interest in developing survey techniques for shallow waters, as exemplified by the International Shallow Survey meetings organized by the Center for Coastal and Ocean Mapping at the University of New Hampshire, and at the Defense Science and Technology Organization in Sydney, Australia. One of the biggest future challenges for acoustic mapping engineers will be to develop a system that can obtain swath coverage in shallow water without being prohibitively expensive.

6. Status of mapping in Massachusetts

There have already been several broad scale mapping efforts conducted in Massachusetts; below is a description of these mapping projects. These programs differ in the technologies used to conduct the mapping and in the intended use of the maps; nevertheless, all offer potentially valuable information to marine resource managers.

6.1 Subtidal

Stellwagen Bank and western Massachusetts Bay

Stellwagen Bank is a National Marine Sanctuary located in the federal waters portion of Massachusetts Bay. The NOAA National Marine Sanctuary program was interested in mapping the distribution of various habitat types on Stellwagen Bank for managers and researchers. The Sanctuary partnered with USGS to produce maps of the Stellwagen Bank and western Massachusetts Bay regions at a scale of 1:25,000 (Fig. 5).

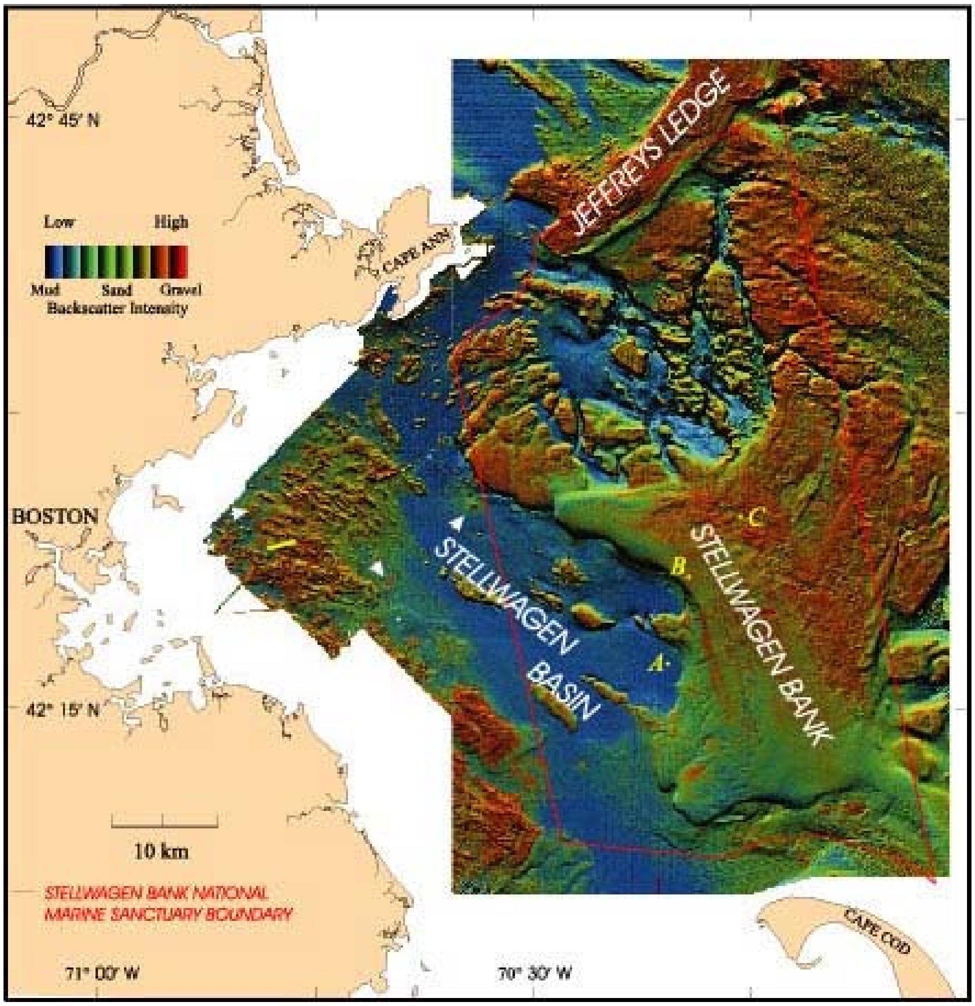

Figure 4: USGS map of acoustic backscatter intensity due to variation in sediment type draped over topography of Stellwagen Bank National Marine Sanctuary and western Massachusetts Bay. Data were obtained from a multibeam survey. White arrows indicate locations of disposal sites; the Massachusetts Bay Disposal Site is near the Sanctuary boundary. The yellow rectangle is the location of Massachusetts Water Resource Authority's sewage outfall. Map available online at: http://pubs.usgs.gov/factsheet/fs78-98/.

The *Frederick G. Creed*, a Canadian Hydrographic Service vessel, was used to conduct the multibeam surveys. Four cruises between 1994 and 1996 were conducted to complete the multibeam survey of the approximately 3900 sq. km study area. Groundtruthing was accomplished using the USGS SeaBOSS.

Dr. Page Valentine at USGS is creating benthic habitat maps of the Stellwagen Bank Sanctuary. The maps are compiled by using multibeam topographic and backscatter imagery along with geological and biological samples, video and photographic images, and seabed texture analyses. As a part of this effort, Dr. Valentine and others are developing a marine habitat classification system suitable for subtidal waters in the Gulf of Maine. While the habitat maps of Stellwagen Bank are still under development, the existing bathymetry and sediment layers have been used to site a fiber optic cable that passes through the Sanctuary.

Massachusetts Bay Disposal Site

In conjunction with the Stellwagen Bank surveys, NOAA and USGS worked together to characterize the seafloor of the Massachusetts Bay Disposal Site. The disposal site is located 17 nautical miles from the entrance to Boston Harbor and is adjacent to Stellwagen Bank National Marine Sanctuary (Fig. 5). A large variety of material had historically been disposed at the site, including dredged material, munitions, construction materials and low-level radioactive waste. Video and still photographs were used to groundtruth the acoustic survey data. Sediment profile imagery was also used to characterize the seafloor habitat at 26 stations within the disposal site. Maps of the site at 1:10,000 scale were published by USGS; they can be used to assess the condition of the site and to monitor the recovery of the benthic community.

Dredged Material Management (SAIC/CZM/ACOE)

Habitat mapping was conducted in several areas of Massachusetts to determine their suitability for dredged material disposal. CZM contracted various consulting firms to assist in mapping potential dredged material disposal sites in New Bedford Harbor, Gloucester Harbor, Salem Harbor, Fall River and Buzzards Bay (see reports at: http://www.mass.gov/czm). In addition, the ACOE conducted habitat mapping at two existing dredged material disposal sites in Cape Cod Bay and Massachusetts Bay in conjunction with NOAA and USGS. The methods were generally similar at all of the sites. Bathymetry was determined using either an echosounder or multibeam sonar. When multibeam sonar was used, the backscatter was retained and used to infer the distribution of various sediment types. Sub-bottom seismic profiling was used to determine the relative thickness of distinct geological layers and the depth to the bedrock at several sites. Groundtruthing was accomplished using grab or core samples to determine sediment grain size and the abundance of infaunal organisms. A series of sediment profile photographs were also taken to determine a number of physical and biological factors including: the substrate type, grain size, depth of the redox layer (estimate of surficial sediment oxidation), bedforms, the organism/sediment index and the depth of penetration of the camera into the sediment. Diving studies were also frequently used to describe physical (e.g., substrate type and topography) and biological (mobile megafauna, sessile epifauna and vegetation) characteristics of the sites. All of this information was combined to determine the suitability of the site for disposal of dredged material (CZM studies) or to evaluate the condition of sites that had already been used for dredged material disposal (ACOE studies). Information obtained as part of the dredged material disposal investigations are available on CZM's Massachusetts Ocean Resources Information System (MORIS) database.

Statewide Seagrass

The Wetlands Protection Division of the Massachusetts Department of Environmental Protection (DEP) in partnership with NOAA's coastal change analysis program at the Coastal Services Center and CZM have undertaken a large project to map the distribution of seagrass in Massachusetts (see sample in Fig. 6). Seagrasses serve many ecological functions, including providing habitat for many commercially valuable fishery species. Changes in the distribution and extent of seagrass are a management concern and could be indicative of declining water quality. Eelgrass, *Zostera marina*, is the dominant seagrass species in Massachusetts while widgeon grass, *Ruppia maritima*, occurs in lower salinity areas and can be found in some portions of Buzzards Bay and Cape Cod Bay. Using (1:20,000) aerial photography of the coast, scientists at DEP used a binocular stereoscope to delineate seagrass polygons for the entire state. Groundtruthing of the seagrass polygons was accomplished with surface observations and towed underwater video cameras. The minimal mapping unit of the maps is 20 m, so all beds greater than 20 m in one dimension are depicted. To track changes in the distribution and extent of seagrass beds, updates to the maps are planned on a five-year cycle. This project was initiated in the mid 1990's and there have been two statewide iterations of the seagrass delineation thus far. There are also black and white aerial photographs from the 1950's, which will allow the DEP to conduct long and short-term change analysis. The results of the change analysis could be used to determine where management or restoration actions should be focused. Scientists frequently use these seagrass maps when planning seagrass research and monitoring. Managers also regularly refer to the maps, along with general seagrass guidance on the CD-ROM available from the NOAA's Coastal Services Center, when reviewing coastal development permit applications. For example, the seagrass maps have been consulted in the environmental review process for the proposed Nantucket Sound windfarm. The seagrass maps are available from Massachusetts Geographic Information System (MassGIS).

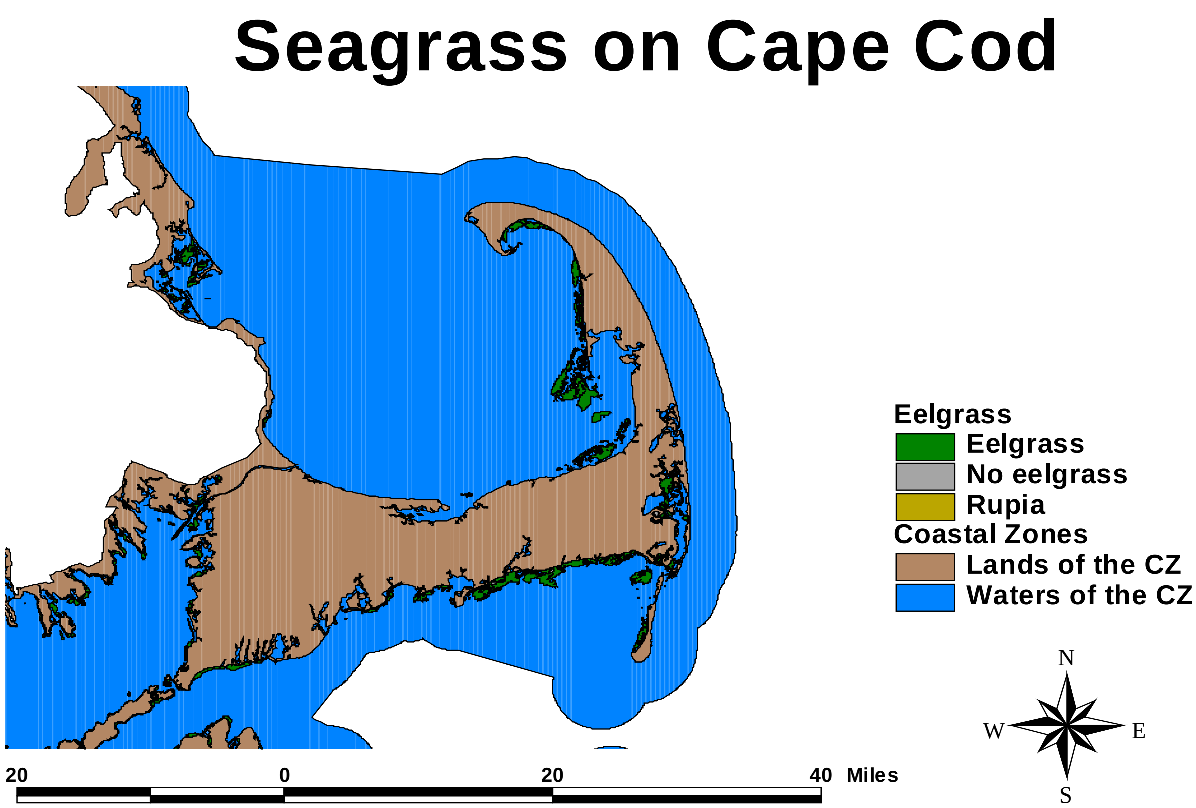

Figure 6: DEP's map of seagrass on Cape Cod. Data were obtained from aerial photography and are available through MassGIS at: http://www.state.ma.us/mgis/massgis.htm.

6.2 Intertidal

Boston Harbor Islands National Recreation Area

Boston Harbor Islands National Recreation Area is a complex of 34 islands located in outer Boston Harbor. In 2001, the National Park Service, through a cooperative agreement with the Island Alliance, contracted the New England Aquarium, Massachusetts Audubon, and USGS, to conduct an intertidal overview and assessment of the Boston Harbor Islands National Park Area. New England Aquarium staff created digital intertidal habitat and substrate maps of 20 of the 34 islands and peninsulas in the Harbor to determine baseline conditions. Substrate types and biotic assemblages, defined by the Boston Harbor Intertidal Classification System, were delineated by walking the perimeter of each habitat with a Differential Global Positioning System (DGPS) (R. Bell, pers. comm.). The maps were used to determine the relative abundance of different substrata and assemblages at one point in time, with the intention that they can be used as a baseline for future changes. The maps will enable park managers to make informed decisions regarding resource vulnerability, use of the islands' intertidal zones, and will be helpful for researchers as well as the public. The maps will be available online for downloading (see: http://www.nps.gov/gis/park_gisdata/massachusetts/boha.htm).

Wellfleet Bay

Wellfleet Bay is located on the bay side of Cape Cod and is adjacent to the Cape Cod National Seashore. The National Park Service conducted mapping of intertidal habitats in Wellfleet Bay in an effort to plan sampling strategies to assess shorebird populations. Researchers from the University of Rhode Island delineated 9 habitat types based on 1995 1:20,000 true color aerial photographs of the region (Fig. 7). The polygons were created on screen by heads-up digitizing and representative polygons were groundtruthed in the field to insure that the habitat identifications were correct. These maps will be used to examine the association between various species of shorebirds and distinct habitat types and will assist managers in the protection of important shorebird habitat while balancing other potential uses of the bay, such as aquaculture. The Wellfleet Bay intertidal habitat maps are available on MORIS.

Wellfleet Harbor Intertidal Habitat Types

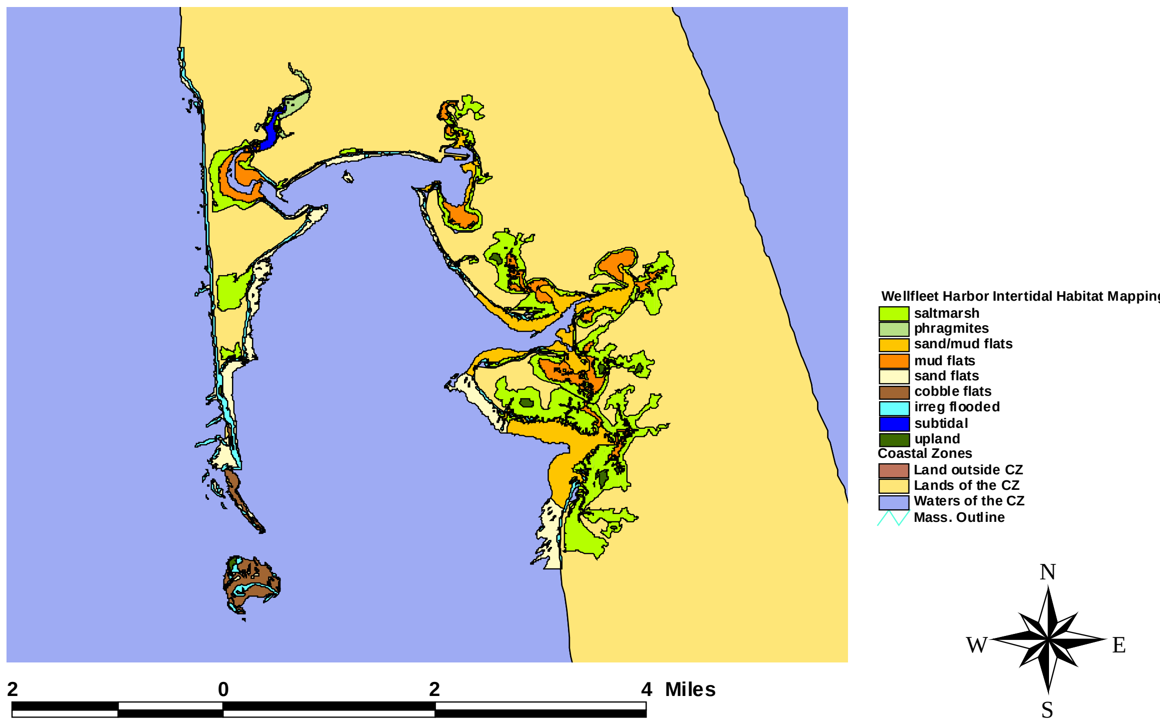

Figure 7: Intertidal habitat types as delineated from aerial photographs by researchers at the University of Rhode Island and National Park Service.

Exemplary Natural Marine Communities

As part of an effort to identify exemplary natural communities within Massachusetts, MNHESP contracted a marine ecologist, Robert Buchsbaum of Massachusetts Audubon, to identify exemplary natural intertidal and shallow subtidal communities throughout the Commonwealth. The communities were based on Swain and Kearsly's (2000) *Classification of Natural Communities of Massachusetts*. Dr. Buchsbaum used his familiarity with coastal habitats of Massachusetts, discussions with other ecologists and coastal managers, and published literature to identify the best representations of these communities. The MassGIS 1:5000 wetlands and streams layer was used to delineate the communities. Often this involved merging several polygons from the wetlands layer and using best professional judgment to determine actual boundaries. A total of 16 exemplary natural communities, of eight different types (e.g. rocky shore, salt marsh, brackish tidal marsh) scattered throughout the state were identified (see example in Fig. 8) and included in the Natural Heritage & Endangered Species Program (NHESP) BioMap of exemplary natural communities across the Commonwealth (see below). The data layer, which is now part of the MassGIS database, includes a description of each community, some of its major physical and biological features, the threats it faces, and supporting documentation, including citations of published reports. The identification of these exemplary natural marine communities can be used for both management and research in the coastal zone and are available on MORIS.

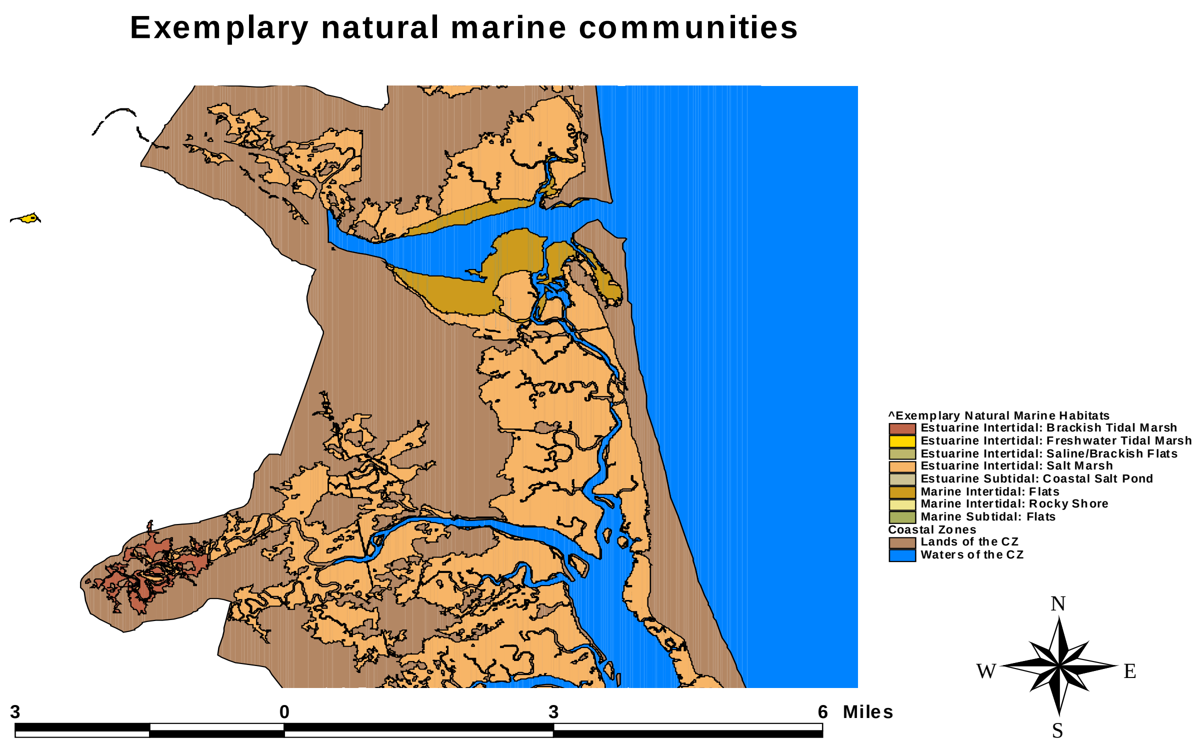

Figure 8: Map of exemplary natural marine communities in Plum Island Sound as delineated by Dr. Robert Buchsbaum of Massachusetts Audubon. Data are available through CZM's Massachusetts Ocean Resources Information System database.

6.3 Terrestrial

BioMap Core habitats

BioMap is a biodiversity mapping project sponsored by Massachusetts' NHESP. It was designed as a guide for land conservation for rare or endangered species. While the major focus of the BioMap program was to delineate the habitats of terrestrial and freshwater organisms, the habitat delineations of some endangered organisms that utilize the marine environment were also completed. Scientists drew core habitat polygons using color infrared photographs combined with information from scientific reports and field observations. The final BioMap coverage is a union of the core habitats of all threatened and rare species that was adjusted to account for recent development projects that may threaten the habitats' integrity. The maps were designed to be used at a scale less than 1:25,000. The habitat polygons of some endangered marine species (e.g. Diamondback terrapin, piping plover) that utilize the intertidal zone or brackish marshes were delineated by the program. In order to extend the BioMap delineations into the subtidal zone, much more information regarding the distribution of various habitat types would be needed. Nevertheless, these maps are potentially useful for marine resource managers striving to protect intertidal habitats that support endangered species and data are available from MassGIS.

DEP's Orthophotograph wetlands and streams

The Orthophoto Wetlands and Streams datalayers are a polygon coverage comprising various wetland types and a line coverage of streams. DEP delineated wetland community types based on interpretation of stereo, 1:12,000 scale, color-infrared photography completed by staff at the University of Massachusetts, Amherst. The resulting maps have a scale of 1:5,000. Some of the community types delineated include: rocky intertidal shore, barrier beach, salt marsh and tidal flat. The various wetland types that are delineated in these maps are for planning purposes only and cannot be used for legal determinations of wetland boundaries. The maps are available from MassGIS.

Priority Natural Vegetation Communities

The Massachusetts DEP delineated different coastal community types based on 1:5,000 color infrared aerial photographs of the coast. The photographs were taken in the spring of 1999 and 2000 and the delineations of the various community types were groundtruthed. The habitat classification system developed for the National Wetlands Inventory was used to classify the various habitat types. There are several different maps displaying various community types in the coastal region. The Coastal Natural Community Systems layer extends from the ocean to the limits of salt spray and delineates communities such as rocky shores, barrier beaches and salt marshes. Some brackish water habitat types are also delineated in the Riverine Natural Community Systems layer. The Coastal Plain Ponds layer has polygons that fall within the boundaries of the lands of the coastal zone. The maps of the coastal natural communities depict the extent and distribution of community types based on their dominant vegetation and will help managers make informed decisions regarding resource use and protection for areas within their jurisdiction. The maps are available from MassGIS and MORIS.

Estimated Habitat of Rare Wildlife

Estimated habitats of rare wildlife have been mapped by the MNHESP. Scientists at MNHESP analyze species' occurrences, population records, habitat requirements and environmental information to delineate the polygons of estimated habitat. This information is combined with maps of different community types (such as those of the priority natural vegetation communities) to select areas of the state that may provide habitat for rare and endangered species. Although the focus of this effort was primarily on terrestrial and freshwater species, some core habitats of marine species were identified. The maps can be used for planning purposes to protect habitat for rare native species and are available from MassGIS or in MORIS.

7. Other mapping in the Gulf of Maine region

Habitat mapping has also been conducted in the Gulf of Maine region. Below is a description of some of the existing broad-scale mapping projects that have been conducted in this region. The various partnerships that have already been successful in mapping portions of the Gulf of Maine could serve as a starting point for further mapping partnerships in Massachusetts waters.

Gulf of Maine Program Watershed Habitat Analysis

The US Fish and Wildlife's Gulf of Maine Coastal Program has undertaken an ambitious effort to map the habitat of 91 species in the Gulf of Maine watershed using habitat suitability modeling. The species whose habitats were mapped were selected because they are federally listed as endangered, threatened or are otherwise a high concern for conservation management. The focus of the habitat mapping was on terrestrial species, especially birds, but some fish species and a marine invertebrate were also assessed. The potential habitat of each species was modeled based on actual sightings or published information regarding the species' preferences for water depth, water temperature, land cover, salinity and substrate types. These environmental requirements were combined into a grid- based habitat suitability model for each species. A ranking system was used to sort the suitability of various habitat types for each species. Conservation groups, planners and managers can use the resulting maps to protect areas that have a high probability of providing habitat to vulnerable species. The maps are available in MORIS and are available on CD-ROM by contacting the Fish and Wildlife Gulf of Maine Coastal Program office (http://www.gulfofmaine.fws.gov).

Jeffreys Ledge

Jeffreys Ledge is a relatively shallow embankment off the coast of Massachusetts and New Hampshire that contains a range of seafloor habitats and is an important fishing ground. Scientists at the University of New Hampshire received funding from the Northeast Consortium and the Cooperative Institute of New England Mariculture and Fisheries (CINEMAR) to conduct habitat mapping on the ledge. The study area is approximately 150 sq. miles, and includes a portion of the Western Gulf of Maine Closure Area, which has been closed to groundfishing since 1997. A multibeam survey of the study area was conducted in January 2003 in conjunction with the consulting firm Science Applications International Corporation (SAIC) using SAIC's *Ocean Explorer* vessel. The backscatter from the multibeam survey will be compared with an existing small-scale sediment map currently available from the USGS. Groundtruthing was conducted using a box corer (for sediment grain size and infauna) and video (for large epifauna). The habitat maps are still under development, but will be used to examine the relationship between groundfish catch and the distribution of various habitat types on the bank.

Great South Channel of George's Bank

The Great South Channel, located off the coast of Massachusetts, separates the eastern side of George's Bank from the western side of Nantucket Shoals. It is a region of high productivity because of its location at the convergence of warm and cold water masses that are also mixed by strong tidal currents. The fishing and shipping industries heavily use the channel and it is critical habitat for the endangered Northern Right Whale. A portion of the Great South Channel, Closed Area I, was closed to fishing in 1994 to preserve groundfish stocks. In 1998, in anticipation of the need for information on the distribution of seabed habitats in the George's Bank region, USGS conducted a multibeam survey of the central part of the Great South Channel. The Canadian Hydrographic Service's vessel, the *Frederick G. Creed*, was used for the survey. It took four days to obtain swath coverage of the 580 sq. km area (water depths ranged between 45 to 100 m). The nearshore area (20-40 m depth) of Cape Cod National Seashore (Chatham to Provincetown Harbor) was also surveyed during transit from the port in Provincetown, MA to the study site.

The map of the multibeam backscatter draped over bathymetry indicated that the seafloor in the Great South Channel is heterogeneous and contains large areas of gravel, a valuable habitat for juvenile groundfish. The multibeam map was used to guide the selection of sections of Closed Area I that could be opened to scallop dragging while avoiding potential juvenile groundfish habitat. A USGS Fact Sheet describing the mapping project can be viewed online (http://pubs.usgs.gov/fs/fs061-01/fs061-01.pdf)

Stellwagen Bank and western Massachusetts Bay

The multibeam mapping described in section 6.1 focused on the seafloor environment within and directly surrounding the Gerry E. Studds Stellwagen Bank National Marine Sanctuary. The majority of mapping was conducted outside of state waters, representing one of the largest mapping projects in the Gulf of Maine.

8. Utilization of existing survey data

Utilization of existing acoustic survey data is a high priority for this mapping plan because it leverages the full utility of data already collected for other purposes. There are several cases in Massachusetts where hydrographic data were recently collected; the backscatter from these surveys could be processed and interpreted to produce maps of surficial geology.

Boston Harbor and approaches

The U.S. National Ocean Survey's Office of the Coast Survey (OCS) is responsible for maintaining and updating navigation charts; they periodically survey major ports to obtain high-resolution bathymetric data. Using mitigation funds received by CZM from the Hubline natural gas pipeline installation into Boston Harbor, CZM and USGS are working together to process existing survey data obtained by OCS. In a 2001 survey of Boston Harbor and approaches, the OCS used the NOAA vessel *Whiting* to obtain multibeam and sidescan-sonar coverage. The eastern edge of the Boston Harbor sidescan-sonar survey adjoins the western edge of USGS' mapping of Stellwagen Bank and western Massachusetts Bay. The OCS' multibeam data were used to determine bathymetry but unfortunately backscatter was not collected. However, the backscatter from the sidescan-sonar will be re-processed and groundtruthed by scientists at USGS for interpretation into a map of surficial sediment distribution. This will include bottom video and still photographs and grab sampling for sediment grain size and infaunal analyses. The resulting bathymetry and backscatter maps will be produced at a scale of 1:25,000 and can be used by CZM and other agencies for planning in this highly urbanized harbor.

Woods Hole Harbor and approaches

OCS conducted a navigation survey of Woods Hole Harbor, Woods Hole, MA and approaches in fall 2001. They simultaneously obtained 100% multibeam and 200% sidescan-sonar coverage, but only retained the backscatter from the sidescan-sonar. The sidescan-sonar data could be processed to determine the sediment distribution, but would require groundtruthing in order to create a habitat map. CZM is currently investigating the feasibility of obtaining this backscatter data for potential processing into a map of surficial sediment distribution.

9. Criteria for prioritizing areas for mapping

One of the most important criteria for prioritizing habitat mapping should be the needs of the various stakeholders. Regions that are heavily used by commercial fishermen or that are subject to potentially high impact activities such as aquaculture, sand/gravel mining, windfarms, shipping or cable/pipe laying should be the highest priority for habitat mapping. In addition, the needs of fisheries researchers and other scientists should be considered when prioritizing areas to be mapped. Another consideration for prioritizing broad-scale mapping is the bathymetry of the areas to be mapped. The swath width of acoustic instruments decreases with decreasing water depth, therefore surveying in deeper water is generally more cost effective than in shallow water. Generally, the nearshore areas are most heavily utilized by humans, and thus need the most management oversight to insure their continued health and productivity. As evidenced by the CZM/USGS partnership to process existing OCS survey data for Boston Harbor, opportunities to process backscatter for existing or planned surveys leverages the full utility of the data, making it useful to a wider audience. Opportunities to capitalize on existing survey data should be considered high priority because of the significant cost savings that could be realized. Finally, in order to ensure continuous coverage, gaps in areas that have recently been mapped should be filled before shifting the mapping effort to a new region.

10. Areas to be mapped in near future

The broad scale of the National Marine Sanctuary/USGS mapping efforts in Stellwagen Bank and western Massachusetts Bay resulted in coverage of a large portion of Massachusetts Bay. CZM is partnering with USGS to complete habitat mapping in portions of Massachusetts Bay using mitigation funds from the construction of a natural gas pipeline.

Massachusetts Bay

Two major sections of Massachusetts Bay were surveyed during the fall and winter of 2003/04 (Fig. 9). One section (section 1) that extends from north of Cape Ann up to the New Hampshire border, was mapped with multibeam sonar using SAIC's vessel the *Ocean Explorer*. The survey ended near the western edge of the University of New Hampshire's mapping of Jeffrey's Ledge and it adjoins the northwest corner of the Stellwagen Bank mapping. The comparatively shallower South Essex Ocean Sanctuary (which extends from Cape Ann to Boston Harbor) (section 2) was surveyed using interferometric sonar, sidescan-sonar and high-resolution seismic profiling by USGS in fall 2003 and spring 2004. The deep end of the survey area in the South Essex Ocean Sanctuary adjoins the northeast border of the USGS mapping in Massachusetts Bay and the survey extends up to the 10 m isobath. Sections 3-10 in figure 9 have been demarcated for planning purposes, and as funds become available, they will also be mapped.

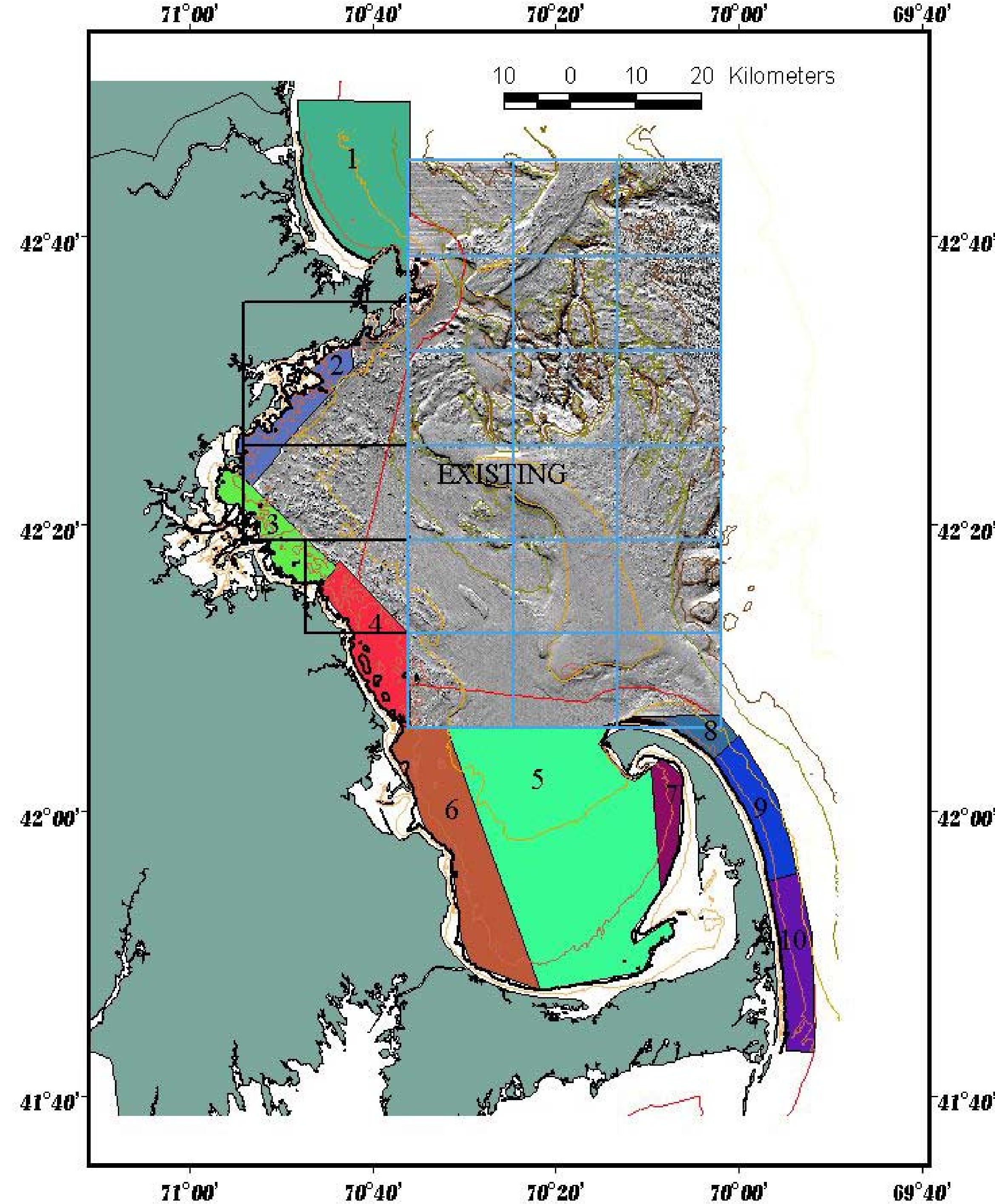

Figure 9: Map showing extent of current and proposed mapping for waters greater than 10 m depth in Massachusetts' Acadian province (source Brad Butman, USGS).

10.1 Other high priority areas for mapping

Table 2: Geographic areas of Massachusetts that remain to be mapped and considerations.

Geographic area	Marine habitat management considerations	Logistical concerns	Other issues
Mt. Hope Bay	Power plant effluent Combined sewer overflow Low dissolved oxygen Eutrophication	Very shallow	Liquified natural gas Desalinization plant
Buzzard's Bay	Recent oil spill Heavy shipping traffic PCB contamination in New Bedford Harbor Eutrophication Seagrass declines	Very shallow	Navigation planning Dredged material management Transition between Acadian and Virginian province
Nantucket Sound & Vineyard Sound	Windfarm proposal Increasing abundance of invasive algae *Codium fragile* Seagrass declines	Shallow	Potential partnership for mapping with Office of Coast Survey
Outer Cape Cod (Fig. 9., sec 8-10)	Cape Cod National Seashore		Mapping partially complete Transition between Acadian and Virginian province
Cape Cod Bay (Fig. 9., sec 5-7)	Right whale critical habitat Seagrass declines		Transition between Acadian and Virginian province
MA Bay (Fig. 9., sec 3-4)	Major sewage outfall Stormwater management	Shallow	Almost completely mapped

Partnerships for seafloor mapping are expected to change over time, but the following is a rough prioritization of the remaining state waters to be mapped. Completion of mapping in Massachusetts Bay is a high priority because a large portion of the Bay has already been mapped, and because this area experiences high development pressures (Fig. 9: sections 3 and 4). Sections 5-7 in Cape Cod Bay (Fig. 7) are the next highest priority areas to be mapped because they also experience heavy use and mapping these sections would provide complete coverage from the northern side of Cape Cod up to the northern border of the state. This area has also been designated critical habitat for the endangered northern Right Whale. The eastern edge of Cape Cod is the next highest priority area to be mapped; a portion of the eastern edge is mapped and additional mapping and groundtruthing would provide a continuous coverage of the outer Cape that would overlap with Massachusetts Bay mapping. Cape Cod is the transition zone between the Acadian and Virginian provinces and therefore, the sediment composition and bathymetry in this region may be distinct from that of the rest of the Commonwealth.

To complete coverage of Massachusetts state waters, the region south of Cape Cod should be mapped. The seafloor environment in this region is presumably more homogenous than the Acadian province because it was not glaciated in the last ice age. Buzzards Bay, Vineyard Sound and Nantucket Sound are also relatively shallow, and therefore it may take longer to complete mapping in this region as compared to Cape Cod Bay and the eastern side of Cape Cod. Interferometric sidescan or LIDAR/CASI may be most suited for these shallow water regions.

11. Recommendations for conducting benthic habitat mapping in Massachusetts

Below is a description of suggested methods to conduct broad-scale benthic habitat mapping in Massachusetts. CZM should assemble a technical advisory group to provide input throughout the planning, data acquisition and data interpretation process. The technical advisory group should be composed of scientists and managers to insure that the end products are useful in a management context. To insure coordination among various state agencies that are likely to conduct benthic habitat mapping, the membership of the technical advisory group should include representatives from CZM, Massachusetts Division of Marine Fisheries (DMF / Marine Fisheries), NHESP, DEP and the Department of Conservation and Recreation.

11.1 Desired scale and resolution

The resolution of the data (sampling density) influences the scale at which the final map is printed. Unlike paper maps, digital data has no inherent scale; it is stored at a scale of 1:1 and can be printed or displayed at any scale. It is possible to misinterpret spatial data in GIS by zooming in to a finer scale than is appropriate for the resolution of the data. The resolution of data gathered by acoustic or optical methods is very high for detecting the presence of seabed topological features and changes in sediment texture. However, various patches of seafloor at the same depth with similar sediment types may have different benthic community types. Therefore, the design of the groundtruth sampling program must be based on methods that allow interpolation between groundtruth sampling stations and have a consistent minimum sampling density for all areas that are mapped (more on groundtruth sampling design in section 11.4). The metadata for all maps that will be produced as part of this initiative should clearly state the resolution of the acoustic data and the groundtruth sampling and the minimum/maximum scale at which the data should be displayed. In addition, explanations for the appropriate use of the maps should be included in the metadata.

The major dissemination method of the maps produced as a result of this initiative will be on CZM's MORIS (Massachusetts Ocean Resources Information System) GIS database. However, some paper maps will likely have to be printed for distribution to stakeholders who lack access to a high speed internet connection. These paper benthic habitat maps should be printed at a scale of 1:25,000. 1:25,000 allow site-specific features (such as kelp beds) to be displayed and is considered a desirable resolution for nearshore habitat mapping (Kvitek et al. 1999). Similarly, Valentine et al. (in press) suggest that sublittoral benthic habitat maps be produced in a range of scales from 1:25,000 to 1:100,000. The habitat mapping project on Stellwagen Bank utilized the 1:25,000 scale, and is considered a benchmark for other coastal and marine habitat mapping projects. 1:25,000 should be the target scale for Massachusetts' nearshore marine habitat mapping unless finer scale data acquisition (1:10,000) is needed for a particular purpose. For less heavily utilized areas of the Commonwealth's waters, such as the middle of Cape Cod Bay, a smaller scale (1:50,000) may be sufficient for management purposes.

Map accuracy assessment

The benthic habitat maps created as a result of this initiative will be used to facilitate management decisions. Therefore, both the positional and thematic accuracy of the maps must meet high quality assurance standards. For positional accuracy, all benthic habitat maps produced by this initiative should meet the National Map Accuracy Standards (http://mapping.usgs.gov/standards/). Thematic accuracy of the benthic habitat maps (the reliability of the habitat classification) will depend on the methods used to delineate habitats. Theoretically, the statistically based method of habitat classification described below should reduce the subjectivity in assigning habitat classifications. The National Park Service is using a 90% thematic accuracy as their standard for vegetation mapping (http://biology.usgs.gov/npsveg/aa/toc.html), this mapping initiative should strive to meet the same standards as both mapping programs are using the maps to make natural resource management decisions. For further information on procedures to calculate thematic accuracy assessment, see Congalton (1991).

11.2 Recommendations for data acquisition using remote sensing methods

Specific recommendations regarding data collection procedures for conducting seafloor geological mapping using remote sensing methods in Massachusetts are described below. Because water depth exerts a strong influence on the efficiency of survey equipment, the recommended equipment is determined by water depth (Table 3). A first step to conducting benthic habitat mapping is to determine the geologic framework of the seabed (surficial geology, bedforms, etc.) and seafloor topography (full coverage bathymetry). Afterwards, groundtruth sampling needs to be conducted to facilitate interpretation of visually or acoustically distinct regions and to obtain information about the benthic community.

Table 3: Approximate area of Massachusetts' coastal zone waters broken down by depth categories. Bathymetry data were derived from USGS Open File Report 98-801 and jurisdictional boundary data from MassGIS.

	Depth (m)	Area in sq. miles (sq. km)
	0 to -5	388 (1,006)
	-5 to –30	1546 (4,005)
	> -30	576 (1,493)
Total Area Coastal Waters		2511 (6,504)

Several general guidelines should be followed to insure that the acoustic data collection effort will produce consistently high quality results. Acoustic surveys should be conducted at times of the year when the signal will not be warped by strong thermoclines. Additionally, a small proportion of survey tracklines should be run perpendicular to the predominant tracklines to image seafloor features that are oriented parallel to the predominant tracklines. Overlap of survey track lines is necessary for both multibeam and sidescan systems because errors increase at the outer range of the swath (Limpenny and Meadows 2002). The degree of overlap between tracklines should be approximately 25% of the swath width in keeping with standards used by USGS for acoustic surveys.

The Federal Geographic Data Committee (FGDC) is establishing National Spatial Data Infrastructure (NSDI) policies and procedures to insure the compatibility of federally funded data collection. The NSDI addresses metadata standards, interchange formats, and data dissemination through a national geospatial data clearinghouse. All data collection for a statewide benthic habitat collection program should comply with the NSDI standards to insure their transferability and accessibility. Details of the NSDI strategy are available at: http://www.fgdc.gov/nsdi/strategy/strategy.html.

<u>Intertidal zone</u>

The Massachusetts DEP have used aerial photographs to delineate intertidal habitat types (see description of DEP's wetlands and streams mapping in section 6.3) and verified aerial photography analyses with field surveys. Aerial photography is suitable for intertidal habitat mapping if the photographs are taken at or near low tide, thus allowing the full extent of the intertidal zone to be photographed and classified into various habitat types. DEP's habitat maps of the intertidal zone provide a foundation to assess the distribution and amount of various intertidal habitat types. However, the habitat classifications may not be detailed enough to suit some management needs (e.g. all rocky intertidal zones are grouped under one category, regardless of the sizes of the dominant substrate). The maps should be inventoried to look for gaps in coverage and the photographs should be repeated periodically (~5-8 years) to examine changes in the type or extent of intertidal wetlands. The utility of CASI for obtaining highly accurate maps of vegetated intertidal habitats could be explored in a small section of the Massachusetts coast following the methods of Larsen and Erickson (1998). CASI derived data would help to discriminate between various types of algae, especially to discriminate between the invasive green algae, *Codium fragile* ssp. *tomentosoides* and native fucoid algae such as *Ascophyllum nodosum, Fucus vesiculosus* and *Fucus spiralis*.

<u>Shallow subtidal (to 5 m below lower low water)</u>

Benthic habitat mapping in the shallow subtidal zone can pose the greatest technological challenge because acoustic equipment has a very narrow swath width in shallow water. Newly developed multibeam systems can operate in water as shallow as 2 m deep. However, the narrow swath width can make utilization of this technology in shallow water cost prohibitive. In addition, the macroalgae and seagrasses that are common in the shallow subtidal can interfere with the acoustic signal and pose entanglement hazards for the equipment. An alternative method to obtain bathymetry and backscatter is to use LIDAR in combination with CASI. The combination of these two methods should be cost effective to map the seafloor in the majority of Massachusetts' waters less than 5 m deep. For areas of the coast where water clarity prohibits the use of CASI, acoustic methods (interferometric sonar) will have to be used to differentiate substrate types.

Aerial photography is another method employed to map features of the seafloor in shallow subtidal areas. As described in Section 6.1, Massachusetts DEP maps the distribution of seagrass throughout Massachusetts waters using aerial photography and extensive groundtruthing. CZM, DEP, NOAA's Coastal Service Center and NOS tested an approach to identify seafloor characteristics in Wellfleet Harbor using aerial photography, RoxAnn and groundtruth sampling (Ferguson 2001). This project demonstrated the utility of using aerial photography to distinguish shallow water habitats. While aerial photography does not provide bathymetric data, surficial geology can be mapped using aerial photographs following protocols used by DEP to map seagrass sufficient groundtruth sampling.

Remote sensing technology is rapidly evolving and shallow water mapping techniques are the focus of substantial research. As technology becomes available, CZM will evaluate effectiveness and promote large-scale mapping in Massachusetts shallow waters.

Subtidal (5 –30 m)

A variety of acoustic sensors can be used to obtain backscatter and bathymetry in these water depths. The USGS has a 234 –kHz interferometric sonar instrument that acquires backscatter and bathymetry. It is operational at shelf depths, however, the 234 –kHz system is primarily used in water depths less than 40 meters. In addition, other commercially available multibeam systems could be used in water of this depth range. The surficial geology information obtained from either sidescan-sonar or multibeam backscatter should be complimented with sub-bottom profiling to investigate the depth of various geologic layers and to define the geologic framework of the region. This depth strata represents the majority of the area of state waters (Table 3).

Deep subtidal (>30 m)

Multibeam sensors are best suited for mapping in waters at least 30 m deep. For waters 30-150 m deep, a multibeam system with 100-250 KHz frequency provides data of a sufficient resolution to interpret surficial geology for habitat mapping. For waters >150 m deep, multibeam with lower frequency (range 30-100 KHz) would still provide data at a suitable resolution while its wider swath width would insure its cost effectiveness. All surveys in waters >30 m deep should also have sub-bottom profiling conducted in conjunction with the multibeam operations. There are approximately 1400 km^2 of state waters that fall into this depth category (Table 3).

Factors that influence costs for data acquisition

The approximate cost of acquiring LIDAR/CASI data in the 1006 km^2 area of the shallow subtidal zone is $7 million dollars. As previously mentioned, the cost of acquiring acoustic data for seafloor habitat mapping is highly dependent on the depth of the water. In addition, the port that the vessel uses, transit time, stratification in the water column and weather considerations all strongly affect the efficiency of vessel based surveys. Even a rough cost calculation of acoustic ship-based surveys need to incorporate detailed information regarding home ports, time of year that surveys will be conducted, etc.; therefore a realistic cost estimate for acoustic surveys is not possible.

11.3 Map products

Habitat mapping that is conducted using the acoustic or optical equipment recommended above could produce four map products. The first map produced would show detailed topography using data obtained from the bathymetry soundings and incorporating calculations of slope, aspect and rugosity/roughness. The second map would show seafloor surficial geology using the sediment texture data derived from acoustic or optical backscatter. The third map would show surficial geology draped over topography. Finally, the fourth map should combine the results of the biological sampling with the physical sampling and show benthic habitats draped over topography. The actual groundtruth locations would be indicated on the benthic habitat map so that users can see how the groundtruth sampling points influenced the interpolation of polygons of different habitat types (see section 11.4).

11.4 Groundtruth procedures

Groundtruth sampling design

Groundtruthing can add significant time and expense to a mapping effort because analyzing infauna samples or photographs requires many hours of human effort and therefore incurs substantial additional costs. Nevertheless, the importance of groundtruthing remotely sensed data must be recognized, regardless of the sophistication of the technology that was used to obtain it. Software that automatically classifies the spectral signature of digital photography or backscatter is being developed by various groups and may reduce the cost of groundtruthing, but these programs should be considered experimental and need to be tested and verified in each unique ecosystem. Bathymetry data obtained by multibeam or interferometric sonar should be checked against bathymetric readings from a single beam echosounder.

Interpretation of backscatter (which is indicative of substrate type) obtained from acoustic or optical technologies requires groundtruthing or verification of results obtained by indirect means. The ICES marine habitat working group has developed some guidelines for conducting groundtruthing. They suggest that sites for groundtruthing be selected based on their acoustic (or optical) backscatter signatures; strictly random sampling design is comparatively less efficient. Therefore, backscatter values should be the primary basis for stratification of groundtruth samples for this benthic habitat mapping initiative. Bathymetry should be an additional consideration when designating sampling strata because of the strong influence of water depth over to composition of benthic communities. For each polygon encompassing a distinct range of backscatter values, subdivisions should be made along 5 meter depth contour intervals. Probability based estimation of the area of distinct habitats can be made by randomly selecting groundtruth sampling points within each polygon representing a range of backscatter values and depth. This stratified sampling approach will allow calculation of confidence intervals of the area of each habitat type (thus allowing change detection- Bailey et al. 1998).

Processing groundtruth samples, particularly for infaunal invertebrates, is costly. Nevertheless, a minimum groundtruth sampling density must be employed for all benthic habitat mapping produced as part of this initiative to insure that all maps meet minimum standards for use in management decisions. A minimum of one groundtruth sample per square kilometer should be the minimum sampling density for statewide benthic habitat mapping. The minimum number of randomly selected groundtruth sampling points per unit area should be supplemented with additional sampling points based on examination of the backscatter obtained from acoustic or optical surveys. Specific areas that appear highly heterogeneous in the backscatter should have a higher proportion of groundtruth samples.

Biological groundtruth sampling

There are many types of sampling to conduct biological groundtruthing such as: photography or videography, grab samples, trawls, sediment profile imagery and visual observations in quadrats or along transects. Different types of equipment are needed to sample infauna, sessile epibenthic species and large mobile organisms. A vital consideration for groundtruth sampling is that the type of gear used to collect biological data strongly affects the results obtained. For example, trawls will yield vastly different species composition data than grab samples; therefore careful consideration of the type of equipment to be used for groundtruthing statewide benthic mapping data is necessary. In addition, high quality biological resource assessment data collected through existing agency and university sampling programs should be incorporated during the data analysis process to leverage these data to the fullest extent. For example, although the data from DMF's trawls is intended for use in population assessments, it could also be examined for coarse-scale interpretation of fish distributions and their correlation with sediment distributions (similar to the analysis conducted by Auster et al. 2001).

Groundtruth sampling to characterize both infauna (grabs, cores or sediment profile imagery) and sessile epibenthic species (planview digital imagery or suction sampling) should be conducted at all groundtruth stations. A planview digital image (still or video) of a known area of the seafloor should be taken prior to the infauna sampling. The percent cover of vegetation and/or colonial sessile epifauna in the digital image should be analyzed using standard point contact methods or image analysis software. Counts should be made of larger, easily identified species. The infauna samples should be analyzed for sediment grain size and organic content, abundance of benthic organisms (counts and/or biomass) and possibly concentrations of contaminants. A photograph of the organisms in the infauna sample should also be taken and stored with the data. Short digital video transects should also be used to examine seabed morphology in acoustically distinct regions, because this attribute can exert a strong influence on community assemblages (Brown et al. 2001). Water clarity is generally greatest at slack tide, therefore video surveys in shallow water should be timed to correspond with slack tide to the maximum extent possible.

If the budget permits, additional groundtruth sampling could include sediment profile imagery (in soft substrates), short resource assessment trawls and transects of acoustic ground discrimination systems. Sediment profile imagery provides information about the successional stage of the benthic community, which indicates the existing level of disturbance. To characterize bottom communities, Brown et al. (2002) recommended towing a 2 m beam trawl for 200-800 m with a warp distance three times the water length and a maximum speed of 1.5 knots. They recommended recording the vessel speed and coordinates every five seconds during the trawl to trace the vessel's trackline. An acoustic ground discrimination system could be used to collect data between groundtruthing stations to facilitate interpolation between points.

Univariate community metrics, such as species richness and diversity indices, should be calculated for all biological groundtruth sampling. These metrics are commonly used in biological data analysis and they will provide information about the quality of various benthic habitats. These metrics can be added into the multivariate analysis (see below) for distinguishing distinct habitat types.

11.5 Data mining and data standards

Data mining is an important component of this mapping initiative because it could save money and effort on groundtruth sampling and facilitate assessment of benthic community types. CZM has already undertaken a data mining effort to identify large data sets where either mapping has taken place or spatially referenced data relevant to marine habitat quality has been obtained. For example, USGS, Massachusetts Water Resources Authority, Environmental Protection Agency, and CZM have each conducted sediment texture sampling within state waters. The information derived from these samples can supplement the groundtruthing data collection and reduce duplication of effort for factors such as sediment texture that are generally consistent over decadal time scales (except for times when large storms rework seafloor substrates). Other data, such as species composition and abundance, are more likely to vary substantially over decadal time scales; therefore this type of data should simply be referenced as a comparison for trends analysis.

The habitat maps that will be generated by this initiative will be used for management decisions such as preliminary site assessments, and therefore all survey and groundtruth data must comply with high data standards. The methods for collecting biological samples should follow standard resource assessment protocols. Specific proposed projects will most likely require additional, directed sampling in the project area to address the particular environmental impacts of the proposed project. While integrating data collected for other projects is desirable because of the cost-savings, the scale at which the data were collected/interpreted and the goal of the particular studies are critical considerations. For example, Gulf-wide models of current flows are unlikely to be relevant in sheltered embayments and therefore extreme caution must be used when layering maps and models intended for use at different scales.

11.6 Data analysis procedures

Delineation of habitat types

In order to insure that the delineation of various habitat types is as objective and repeatable as possible, multivariate statistical methods should be used. In an effort to groundtruth data from a multibeam acoustic survey, Kostylev et al. (2001) used multivariate statistics to define clusters of stations with similar habitats. Frietas et al. (2003) also used multivariate statistics to classify acoustic data into various categories of benthic habitat types. Delineation of various benthic habitat types in Massachusetts should follow the general approach of Kostylev et al. (2001), but slightly different statistical methods should be employed. Briefly, the physical (depth, substrate) and biological (vegetation and fauna) data should be entered into multivariate statistical software such as PRIMER (Plymouth Routines in Multivariate Ecological Research, Plymouth Marine Lab, UK). PRIMER is a statistical package especially designed for analysis and synthesis of community data and is owned by CZM. Cluster analysis and non-metric multidimensional scaling (MDS) should be performed after appropriate data transformations are conducted. Unsupervised classification of the groundtruthing stations into habitat types should be based upon natural groupings of sampling stations that are expected in the MDS plot. The cluster analysis can be used to clarify the groupings of the individual stations. The species that contribute the most to the differences in the data (discriminant species) can be determined using similarity percentages program (SIMPER). Further statistical manipulations examining the relationship between physical variables (sediment grain size, depth) and community structure may be performed following the methods of Brown et al. (2001).

As previously mentioned, the use of multivariate statistics to define habitat types reduces the need for a habitat classification system. However, if the separation of groups is not clear, a habitat classification system should be employed to provide guidance on the separation of various habitat types. The habitat classification system developed by Valentine et al. (in press) has been used to in the development of benthic habitat maps in Stellwagen Bank and other sublittoral marine environments in Northeastern North America. This applicability of the Valentine et al. (in press) habitat classification system for coastal sublittoral environments could be examined through the groundtruthing conducted for this mapping initiative.

Interpolation methods

Spatial analysis should be conducted to draw polygons of the various habitat types in GIS. There are various methods to interpolate point data (such as is obtained from groundtruth samples) to continuous polygons of habitat types. Kriging, spline and inverse distance weighting are three interpolation techniques that could be used to create the final habitat maps. The specific type of interpolation method most suited to create the polygons will depend on the density of sampling points. Nevertheless, to reduce the subjectivity of the process, spatial statistics should be employed to make polygons rather than manually defining polygon boundaries.

The quality of the resulting map can be examined through subjective methods (does the distribution of habitat types appear logical?) and analysis of similarity (ANOSIM) statistical tests. The groundtruth stations within a particular habitat type should be more similar to each other than those in different habitat types. The use of statistical procedures to define habitat types and to create maps will insure that the methods used to identify various habitat types can be replicated in other locations. The methods proposed for this strategic plan could be transferred to other benthic habitat mapping projects, particularly to others in the Gulf of Maine.

11.7 Data management and map maintenance

Data management plan

Data management is a very important component of the mapping strategic plan. A database management system should be utilized to store and organize the large volume of data that will be obtained from the mapping and groundtruthing. FGDC compliant metadata should be generated for all of the survey data. The metadata should be submitted to a FGDC clearinghouse for inclusion in their database. Data should be archived in its raw form in a transferable format (ASCII) and stored at CZM under the supervision of CZM's data manager. The groundtruthing data should be stored in conjunction with the acoustic or optical data. All of the geospatially referenced photographs (planview of the bottom, organisms in the grab sample and sediment profile image, if applicable) should be linked to the backscatter pixel closest to the groundtruth station. All geospatial data generated by this project should be projected to Massachusetts State Plane, meters, North American Datum 83, in accordance with data available from MassGIS.

The Massachusetts Office of Coastal Zone Management already has a searchable data management system that could be utilized to store and disseminate the data and habitat maps that would be produced by this initiative. The Massachusetts Ocean Resources Information System (MORIS) is a GIS database originally designed as an aquaculture siting tool. MORIS already contains datalayers that depict physical attributes such as large-scale (low resolution) sediment distribution (1:1,000,000 Poppe et al. 1989), biological data (species distribution data obtained for the creation of environmental sensitivity indices) as well as georegulations (laws pertaining to the coastal zone, especially to construction of structures, modifications to shorelines, etc.). MORIS is well suited to incorporate the large volume of data that would be produced by a statewide mapping program. MORIS is web accessible which will insure that the maps and metadata are accessible to a wide audience. In addition, the maps should be distributed through MassGIS, Massachusetts' GIS clearinghouse, as they are produced.

Review/update of maps

Periodic updates and maintenance of habitat maps is necessary because the distribution of sediments and benthic organisms, changes over time. A schedule for the periodic review of habitat maps must be implemented to insure their accuracy is sufficient for management purposes. Groundtruthing can be the starting point for map updates, because shifts in biological data (species composition and relative abundance) are expected to change over shorter time periods than geological data (surficial geology) in the absence of large disturbances such as hurricanes. Communities with long-lived dominant organisms or less frequent disturbance regimes should have less frequent review and updates of mapping and groundtruthing. Another criteria for determining the update schedule should be the degree of human impact in a particular area. For example, nearshore communities are likely to experience more intense development pressures than deeper waters, and therefore habitat maps in heavily utilized areas of the coastal zone should be checked for accuracy and updated frequently (e.g. every five years). Finally, the technologies used to obtain surficial geology and biological data may change with time. Emerging technologies should be fully utilized as long as they provide data that is comparable to existing benthic habitat maps. The data management system must be designed to incorporate several groundtruth sampling dates for the same region in addition to repeated acoustic (or another technology) surveys.

12. Training/orientation to the use of habitat maps

Training on the use of habitat maps will be essential to insure that all of the various stakeholders obtain maximum benefit from the information presented while insuring appropriate use. Training workshops should be held to insure that those who frequently use the maps are aware of their utility and limitations. These workshops should include several case studies showing how the maps can be used to facilitate management decisions. Examples of inappropriate uses of the maps, such as displaying information at a finer scale than the data were obtained, should also be discussed at the training workshops. Finally, the training workshops will provide a forum for mapmakers to receive feedback on the accuracy and utility of the maps from those that will be expected to use them.

13. Agencies/groups that have mapping equipment and expertise

Massachusetts has the benefit of being located in a region with a high concentration of centers of mapping expertise, which will facilitate the implementation of this mapping initiative. There are several government agencies, academic institutions and private sector facilities located nearby that can provide equipment and staff needed to conduct this state-wide mapping program.

Government agencies

The seafloor mapping facility at USGS in Woods Hole, MA contains a wealth of both mapping equipment and expertise. There are several geologists and field engineers who carry out data acquisition and interpretation. They have two sidescan-sonar systems: one is a swept frequency (CHIRP) that operates at 100-120 kHz and the other is a dual frequency sidescan-sonar (100/500 kHz). USGS also has an interferometric sonar (234 kHz) and 200 kHz single beam echosounders. The Woods Hole seafloor mapping facility at USGS has several different seismic-reflection systems, each is designed to penetrate into different types of substrates. Finally, the USGS seafloor mapping facility also has SeaBOSS, the specially designed equipment unit for groundtruthing acoustic data.

At the state level, there is currently relatively little acoustic mapping expertise, but CZM is working with USGS to map Ipswich Bay, South Essex Ocean Sanctuary and outer Cape Cod and process the existing sidescan-sonar data for Boston Harbor. The DEP also has staff experienced in delineating communities based on aerial photography, as evidenced by the statewide seagrass and wetland mapping programs. Several state agencies already own equipment suitable for marine seafloor mapping. CZM owns a signal processing single beam echosounder, RoxAnn, for mapping subtidal habitats and DMF has recently purchased a multibeam system that will be deployed from NOAA's research vessel *Gloria Michelle*. Finally, the state of Rhode Island has recently purchased a multibeam sonar and has expressed willingness to collaborate with Massachusetts for seafloor mapping surveys.

Academia

There are several universities in the region that have equipment and staff that could contribute to a state-wide benthic habitat mapping program. Several faculty and graduate students at the University of Massachusetts at Dartmouth have experience conducting scallop habitat mapping. The Massachusetts Institute of Technology has autonomous and remotely operated underwater vehicles that could be used in groundtruthing efforts. The Center for Coastal and Ocean Mapping and the Joint Hydrographic Center (CCOM/JHC) at the University of New Hampshire is a hub of mapping expertise. They have many faculty members, research scientists and graduate students. Staff at the CCOM/JHC have conducted numerous multibeam, sidescan-sonar and single beam echosounder surveys in the Gulf of Maine and elsewhere. In addition, they research methods to improve backscatter processing, shallow water mapping techniques and data visualization methods. The University of Maine and Bigelow Oceanographic Institution have faculty and staff with experience conducting shallow water benthic habitat mapping, especially side-scan sonar surveys. Finally, the University of Connecticut National Undersea Research Center has faculty with habitat research expertise in addition to four remotely operated vehicles and various other types of equipment that could be used for seafloor observations and to obtain groundtruth samples.

Private sector

Several consulting firms in New England have conducted benthic habitat mapping in conjunction with NOAA and USGS. These firms have both the expertise and equipment to assist with the implementation of a state-wide benthic habitat mapping initiative.

Non-Governmental Organizations

Private non-profit organizations are increasingly using GIS to analyze resource distribution for conservation planning. While generally they do not have sophisticated mapping technology, staff members obtain spatially explicit data from the government, academia and other private groups to analyze marine resources.

14. Collaborations and Partnerships

Below are several examples of existing groups and mapping programs that could coordinate with a Commonwealth-wide benthic habitat mapping program. This is not meant to be a comprehensive list of all mapping related groups or programs in the region, but rather to illustrate the types of groups/organizations that are currently conducting mapping or are interested in benthic habitat mapping.

GOMMI

As previously mentioned, the Gulf of Maine Mapping Initiative (GOMMI) is a natural partnership for a Massachusetts state-wide habitat mapping initiative. GOMMI's goal is to obtain the geophysical and biological data needed to produce habitat maps of the entire Gulf of Maine. Website: http://www.gulfofmaine.org/gommi.

GoMOOS and Census of Marine Life

The Gulf of Maine Ocean Observing System offers web-based oceanographic information derived from buoys and satellites. They are also involved in the development of the Gulf of Maine Biogeographic Information System (GMBIS) through the Census of Marine Life's Gulf of Maine pilot program. GMBIS will serve as a clearinghouse for all spatially referenced physical, chemical and biological oceanographic data in the Gulf of Maine. Website: http://www.gomoos.org

Natural Heritage-BioMap

Currently, the BioMap program does not extend into subtidal marine waters because there is much less information regarding species abundance and distributions of various habitat types. The information that would be generated from the surveys and the subsequent groundtruthing would be valuable for conducting an assessment of habitat for rare species types, similar to the BioMap program. Website: http://www.mass.gov/dfwele/dfw/nhesp/nhbiomap.htm

15. Grant opportunities for mapping

Funding opportunities to support benthic habitat mapping are variable, however several potential funding sources are listed below. This is not a comprehensive list of all grant programs that may provide funds to support mapping or habitat/organism relationship research, but rather to highlight some relevant program areas within various grant programs. Proposals that are focused on habitat data acquisition, interpretation or dissemination would likely be suitable for different grant programs or different program areas, which renders benthic habitat mapping eligible for many different funding opportunities.

NOAA's Office of Ocean Exploration

NOAA's Office of Ocean Exploration (OE) funds proposals that seek to expand our knowledge of the physical and biological characteristics of the ocean. Two priority subject areas for OE are: mapping ocean characteristics and bathymetry and characterization of benthic and pelagic habitats and ecosystems. For example, OE funded the use of a remotely operated vehicle (ROV) to characterize benthic habitats of several Pacific coast National Marine Sanctuaries. The emphasis of the OE program is to fund projects in unknown, or poorly known oceanic regions, usually this entails deep water.

Northeast Consortium

The Northeast Consortium was created to foster collaborative research between fishermen and scientists. Equipping fishing vessels with instruments to conduct scientific research is one of the priorities of the program. The University of New Hampshire's habitat mapping (multibeam survey with video and grab sample groundtruthing) of Jeffrey's Ledge was partially funded using Northeast Consortium funds. The Northeast Consortium dictates that all proposals allocate 75% of their budget to the fishing industry and 25% to researchers (website: http://www.northeastconsortium.org/Project_description.html).

Sea Grant

Sea Grant is a nationwide network of university-based programs that is administered through NOAA. Sea Grant funds a variety of projects aimed at improving the stewardship of ocean resources. There are two Sea Grant programs in Massachusetts: one at the Massachusetts Institute of Technology (MIT) and another at the Woods Hole Oceanographic Institution (WHOI). Two of the focus areas of the MIT program that would be suitable for various types of benthic habitat mapping proposals are: coastal management and utilization or technology development. The WHOI program areas that would be most suited for a benthic habitat mapping proposal include: estuarine and coastal processes, environmental technology and public outreach, education and extension.

National Undersea Research Center

The National Undersea Research Center-North Atlantic and Great Lakes (NURC-NA&GL), has two grant programs that could provide funding for comprehensive benthic habitat mapping in Massachusetts. The proposal based research program solicits requests from investigators seeking to increase understanding of the ocean and its resources. The funding limit for science support proposals (travel, salary, costs for sample analysis, specialized equipment) is $50,000 per year for up to two years of support. General at-sea support (vessels, food, berthing) related to operating submersibles and remotely operated vehicles is provided at no charge to investigators. Program development projects are reviewed internally at the NURC-NA&GL and request ROV or diving support for projects that are otherwise fully funded.

NOAA Coastal Service Center

The NOAA Coastal Service Center (CSC) is an office within the National Oceanic and Atmospheric Administration devoted to serving state and local coastal resource management programs. CSC funds a range of projects to improve coastal resource management with several grants available to assess and map marine habitat (http://www.csc.noaa.gov/bins/fellows-funding.html).

Prospect Hill Foundation

The Prospect Hill Foundation is a grant making institution with environmental conservation as one of the program areas. The Prospect Hill Foundation is interested in funding proposals that are aimed at protecting habitat and conserving significant public lands (website: http://fdncenter.org/grantmaker/prospecthill/index.html). For example, they provided grant funds to the Center for Coastal Studies to monitor the impact of Massachusetts Water Resources Authority's sewage outfall on Boston Harbor water quality and to Save the Bay (a nonprofit group located in Providence, RI) to protect portions of Narragansett Bay and its watershed. The foundation might provide funding to characterize the seafloor community in areas that are considered likely to harbor rare or sensitive benthic habitats.

16. Distribution/outreach

The primary distribution method for the benthic habitat maps will be as GIS files through MORIS. Paper maps can be produced for groups that do not have web access or have specialized needs. The MORIS distribution list will be a primary source for persons potentially interested in the maps. Other groups such as: local resource managers, environmental organizations, harbormasters and shellfish constables could benefit from the maps, and they will be notified of their availability through CZM's regional coordinators. CZM's website and *Coastlines* publication will be the primary venues for notifying the public of the availability of the maps.

17. Summary of management applications

As the case studies and the summaries of the various mapping projects illustrate, there are many benefits of conducting habitat mapping for marine resource management. For example, fisheries biologists will be able to assess the availability of suitable settlement and recruitment substrates for various commercially important fish and shellfish species. Resource managers can reference the maps when siting projects such as docks and piers, mooring fields, dredging sites, cable/pipeline routes, aquaculture sites, no wake zone designation and other activities that potentially affect the quality of subtidal habitats. Managers will be able to analyze the amount of different habitat types protected by various protection options (fishery closures, MPA's) and use this as a planning tool to insure future protection efforts are habitat-based and include representatives of all habitat types in a region. A critical need for managers is to assess both the individual and cumulative impacts of human activity on the seafloor. This will be greatly facilitated when the spatial distribution of various benthic habitat types are known.

As maps are produced, the utility of benthic maps is expected to increase and generally improve the efficiency of managing the ocean environment throughout Massachusetts. CZM is committed to promote the value of benthic habitat maps, including bathymetry, surficial geology and marine habitat assessments, to the long-term management of ocean resources and will insure a broad distribution of benthic habitat maps.

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