ESTUARINE BENTHIC MAPPING AS A DECISION-MAKING TOOL FOR RESOURCE MANAGEMENT

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TABLE OF CONTENTS

Page

TABLES AND FIGURES

LIST OF TABLES AND FIGURES

1.0 INTRODUCTION

Mapping of estuarine benthic resources has been used in many regions of the United States as a key decision-making tool to enhance resource management by responsible agencies and stakeholders (Kennedy 1982; Kennish 1990; Ranasinghe et al. 1994; Able et al. 1995; Bruce et al. 1997; Weisberg et al. 1997; McRea et al. 1999; Auster et al. 2001; Allen et al. 2002; Boesch 2000; Linker et al. 2002). Mapping of benthic resources has evolved over the past century from generalized surveys that documented habitat boundaries and distributions of selected species (e.g., for fill and development projects and early scientific studies) to highly accurate Geographic Information System (GIS)-based programs to document the spatial extent and temporal variability of discrete habitats and biological communities (Bobbitt et al. 1997; Robbins 1997; Bretz et al. 1998; Smith and Greenhawk 1998). The accurate documentation and display of this information represents a key tool for use by environmental managers and decision makers in defining baseline conditions; making projections of future conditions, with and without significant natural events and management actions (e.g., best management practices or restoration projects); and monitoring the accuracy of predictions and success of management actions. In this evolutionary sequence of continually improving tools, once novel applications such as GIS and field-based measurements using Global Positioning Systems (GPS) have become commonplace methods, particularly when linked with precision mapping and survey tools including acoustic techniques, aerial imaging, and point sampling, for improving decision-making associated with resource management.

This paper focuses on the value and linkage of mapping to enhance decision-making and resource management. For this review, a "typical" estuarine environment is defined as shallow (less than 25 m) and comprised primarily of soft and/or fine-grained sediments that may be vegetated (e.g., eelgrass or other submerged aquatic vegetation [SAV]) or unvegetated. An overview is provided on regulatory and environmental drivers that directly or indirectly specify mapping to enhance decision-making and resource management of estuarine benthic habitats and resources. Case studies that focus on seagrass and fish/fisheries examples from the West Coast and fish/fisheries and benthic invertebrate examples from the East Coast are used to demonstrate the process and importance of mapping estuarine benthic habitats and resources. These studies include the role of mapping in tracking temporal and spatial changes, both in the absence of human intervention and in relation to habitat and ecosystem improvement programs (e.g., habitat creation or restoration).

2.0 OVERVIEW OF REGULATORY AND ENVIRONMENTAL DRIVERS

Mapping of marine benthic resources in estuarine environments had its principal origins in the early 1900s, primarily motivated by scientific interest in documenting the distribution and abundance of species and habitats. The long history of development and subsequent impacts to estuarine environments during the 1900s, continuing at present although to a lesser extent, also contributed mapping information such as general boundaries. However, mapping of discrete habitats and resources was typically of secondary, if any, interest to early development activities. This pattern has been repeated in most estuarine areas on all coasts, and was only stemmed with the emergence of new environmental activism/awareness and legal mandates (e.g., Goldfarb 1989), beginning on a relatively large scale during the 1970s and continuing to the present.

Primary categories of environmental legislation that address estuaries and their relationship to key subtidal resources (habitats and species) are listed in Table 1, along with examples of specific guidelines developed by agencies in southern California to implement relatively general provisions of this legislation.

Principal federal laws that focus on the protection of subtidal estuarine benthic habitats include Section 404 of the Clean Water Act (CWA) and state coastal zone management policies developed pursuant to the Coastal Zone Management Act (CZMA) (Goldfarb 1989). Oversight and permitting under Section 404 is the responsibility of the U.S. Army Corps of Engineers (USACE), while the National Oceanic and Atmospheric Administration administers the CZMA, as well as the provisions related to Essential Fish Habitat under the Magnuson-Stevenson Act. Those states that have federally approved management plans administer provisions of the CZMA at the state level. Other related laws that provide for protection and management of discrete estuarine resources include the Endangered Species Act, point and non-point source pollution control under Sections 401 and 402 of the CWA, and the sole source aquifer section of the Safe Drinking Water Act. Executive Order 11990 expanded federal oversight to include a goal of no net loss of wetlands and built upon existing mandates of the USACE (Lyon 1993).

Despite the importance of these laws for environmental protection, it is notable that they generally do not include specific requirements for mapping of *subtidal* benthic resources. However, jurisdictional delineation and designation of Waters of the U.S. (e.g., CWA Section 404) require documentation of wetland or high tide boundaries, thereby constituting a mapping "requirement" for the *intertidal* limit of these resources. Nonetheless, mapping of subtidal benthic resources has evolved as a key tool to fulfill the letter and spirit of the listed environmental laws by documenting the spatial extent and temporal changes associated with these resources. Application of these laws can take the form of "guidelines" established by state and local agencies to detail local or regional requirements for compliance and implementation. As examples, the Southern California Eelgrass Mitigation Policy was established (NMFS 1991) in coordination with federal and state agencies to define mitigation ratios for project impacts to eelgrass, and a Memorandum of Understanding (MOU) was established between USFWS and the U.S. Navy to detail commitments to California Least Tern conservation and enhancement in San Diego Bay. This MOU defines, for example, zones and seasons within which the Navy can conduct in-water projects and avoid significant impacts to tern populations. Current mapping programs that are conducted by a range of agencies, stakeholders, and scientists to aid in decision making and resource management represent a continuing legacy of these laws, guidelines, and related activism, along with academic studies that are inspired by applied or basic research interests. Examples include requirements for permitting and monitoring associated with negotiated settlements (e.g., on-site and off-site mitigation of estuaries for project impacts).

Estuarine benthic resources (habitats and species) that are generally covered by environmental laws include special status species (further detailed based on federal and state listed species) and Essential Fish Habitat (e.g., eelgrass, kelp beds, and estuaries). However, an implied underpinning of the relatively general legal requirements for environmental protection and conservation is that the identified resources are comprised of complex physical processes and associations of habitats, species, and communities, or subunits (Day et al. 1989). Successful implementation of these legal requirements and management of resources, therefore, are greatly enhanced by detailed knowledge of these subunits, including mapping at an appropriate scale. Definitions and classifications of estuarine benthic habitats and associated biological resources have been the focus of numerous scientific papers (e.g., Cowardin et al. 1979; Dethier 1990, 1992; Allee et al. 2000). With these subunits (discrete habitats and species) in mind the importance of fine-scale resolution by mapping is apparent, in addition to screening level documentation at relatively larger and coarser scales.

Typical mapping efforts for many estuarine benthic systems include a combination of broad-scale, lower resolution, physical characterization data (e.g., aerial photography, multi-beam bathymetry, side-scan sonar imagery, etc.) as well as fine-scale, higher resolution sampling data (e.g., sediment grabs and fish trawls at discrete stations or along defined transects). Broad-scale techniques are intended to provide a general physical overview (e.g., extent of SAV or kelp bed habitats, bottom topography, changes in surface sediments, etc.) over an area of interest. Fine-scale techniques are commonly used to generate ground-truth data that improve and/or confirm the broad-scale interpretation. Directed mapping programs to fulfill legal and management/stewardship responsibilities of agencies and stakeholders can best be accomplished by documented, defensible knowledge of spatial and temporal changes in these resources.

3.0 APPLICATION AND VALUE OF MAPPING FOR RESOURCE MANAGEMENT

Mapping is critical to document the location of changes in the spatial extent of habitats over established time intervals (e.g., often defined by performance criteria in mitigation and restoration plans), and, particularly for representative and/or special status species, the abundance or density within a spatially defined habitat type. These variables must be documented in association with the impact source(s) that influence the change, whether physical, chemical, or biological. It is significant, however, that documentation based solely on spatial changes (e.g., acreage) does not always account for losses in estuarine function due to the complexity of ecosystem interactions on local and regional scales (e.g., Day et al. 1989). Further, unless mapping is conducted on an appropriate scale with precise geo-spatial controls, the extent of change may not be documented sufficiently to allow statistically valid comparisons and defensible management decisions based on the results.

Mapping of estuarine benthic resources for resource management generally is conducted to accomplish one or more goals including:

- Establish baseline conditions for comparison with past or future conditions, based on projected changes from natural or human-related effects;
- Develop and document engineering plans and determine construction-related impacts and mitigation for estuarine habitats (creation, restoration, and enhancement projects);
- Document changes due to natural or human-related effects to evaluate the success of creation, restoration, and enhancement efforts;
- Document the success of mitigation actions and/or compensation required due to project impacts; and/or
- Document the need for management intervention (e.g., to protect a resource from developing or continuing impacts).

The case studies in the following section provide specific discussion of programs that address these goals.

4.0 CASE STUDIES (SOUTHERN CALIFORNIA AND CHESAPEAKE BAY)

Case studies are described below as examples of the value and linkage of mapping to enhance decision-making and benthic resource management, including subtidal plants (seagrass/eelgrass) and fishes among key variables. The regulatory underpinning of these studies is defined broadly by federal legislation such as the CWA, ESA, and Magnuson-Stevenson Act, augmented in many instances by regional guidelines such as the Southern California Eelgrass Mitigation Policy to define specific requirements for project-related impacts. Benthic mapping is applied specifically to document impacts and fulfillment of mitigation requirements for management and decision making.

4.1 San Diego Bay (San Diego, CA)

San Diego Bay is similar to many large coastal marine estuaries in supporting substantial benthic habitats and resources, including nursery and feeding grounds for numerous fish and invertebrate species and representing productive areas for submerged aquatic vegetation (SAV) such as eelgrass (*Zostera marina*)

(USDN-SWDIV 2000). Eelgrass, as an Essential Fish Habitat, is specifically addressed by the Integrated Natural Resources Management Plan (INRMP) developed jointly by the U.S. Department of the Navy, Southwest Division (SWDIV) and the San Diego Unified Port District (SDUPD) for San Diego Bay (USDN-SWDIV 2000). The INRMP provides detailed guidance on stewardship for natural resources and benchmarks for development of mitigation and evaluation of potential impacts. As such, the INRMP has specific applications for fulfilling resource management goals for documentation of baseline conditions; development of plans for creation, restoration, and enhancement projects; and evaluation of changes (impacts or beneficial effects) due to natural and human-related influences. In particular, mapping of key resources such as eelgrass and fish communities is a key component of management and decision-making goals for San Diego Bay. These goals and fulfillment of regulatory requirements and guidelines focus on evaluation of impacts and mitigation for individual and cumulative projects in the bay, such that programs like eelgrass mitigation banks achieve a net balance for resource management.

This case study focuses on mapping of vegetated areas and associated fishes in representative habitats in accordance with the INRMP, using side scan sonar and fish abundance data to help manage and document the condition of these important resources in San Diego Bay. Dredging of the bay to enhance navigation and commerce has substantially reduced the amount (acres) of highly productive, generally shallow (e.g., < 4 m), vegetated habitat, while increasing the amount of less productive, deep-water habitat (USDN-SWDIV 2000). Mapping of eelgrass beds using side-scan sonar and documentation of fish abundance using trawl collections represents a key management tool to balance development and protection of natural resources.

Eelgrass is surveyed (mapped) to provide baseline densities prior to project construction (e.g., Figure 4.4-1). Following a construction project, eelgrass is mapped again to determine impacts from the project verify specific mitigation requirements (acres of eelgrass). For various U.S. Navy projects in San Diego Bay, the Navy uses a mitigation bank (NEMS: Navy Eelgrass Mitigation Sites) where eelgrass has been planted to offset impacts as part of its bay stewardship. The Navy develops, monitors, and maintains NEMS off Silver Strand, near Naval Amphibious Base Coronado in the central Bay. The NEMS sites were originally established as mitigation for Navy projects, but are surveyed at least yearly and augmented by transplanting eelgrass to maintain an inventory of credits for any new mitigation needs (M & A 2003; K. Merkel, pers. comm.). Maintenance of relatively large eelgrass beds such as the NEMS for mitigation banking is environmentally preferred (better long-term survival) to smaller scale mitigation (eelgrass transplants) that would be necessary for small impact areas in the absence of these banks. Site surveys of the beds utilize a Marine Sonic 600 kHz side-scan sonar correlated by differential global positioning system, with bathymetric data collected using a Furuno FCV-600L single-beam fathometer (200 kHz operating frequency). Monitoring has shown that eelgrass densities at some NEMS sites undergo substantial yearly fluctuations, while others remain relatively stable. For example, eelgrass at NEMS 1 has been generally unchanged since 1990, with densities ranging from 5.78 acres in 1990 to 6.20 acres in 2002 (Figure 4.1-2). In contrast, eelgrass at NEMS 4 has varied substantially, with densities ranging from 0.39 acres in 1994 to a low of 0.047 acres in 1998, then increasing to 1.27 acres in 2001, and declining sharply again to 0.11 acres in 2002. The declines are likely due to El Niño events (1998), as influenced by warmer water temperatures and more storms that had a greater effect on the smaller NEMS 4 bed, and somewhat deeper water than is optimal for long-term growth in part of the site (2002). Management of the NEMS beds relies on accurate mapping to maintain this key resource for long-term planning and decision-making (project approvals as part of environmental documentation, including environmental assessments, environmental impacts statements, etc., and mitigation) for new and cumulative projects in vegetated areas of the bay.

Eelgrass beds in the bay are characterized by diverse and abundant fish communities (Allen et al. 2002; Figure 4.1-3) that occur within a general area designated as EFH by two Fishery Management Plans (FMP): Pacific Coast Groundfish (PFMC 1998a) and Coastal Pelagic Species (PFMC 1998b). Eelgrass beds including the NEMS sites, as sampled using a variety of trawls and seines, support a high abundance of fishes, including northern anchovies, slough anchovies, and topsmelt that are important prey for many demersal species such as sand bass and halibut. Mapping these subtidal benthic resources (eelgrass and fishes) comprises an effective tool for decision-making and management (particularly mitigation of project effects) of these combined resources, as applied for San Diego Bay in conformance with federal and state legislation, agency guidelines, and the INRMP. The balance of project-specific and cumulative effects, as documented by pre- and post-construction mapping, is carefully integrated into approval and permitting processes for projects in the bay.

4.2 Batiquitos Lagoon (Carlsbad, CA)

Batiquitos Lagoon, a mid-sized coastal estuary (about 650 acres) located in northern San Diego County, CA (Figure 4.2-1), was the focus of a highly successful restoration project that relied substantially on mapping to enable decision-making and resource management. In particular, mapping helped document declining habitat and resource values (e,g., reductions in acreage and species abundance), ultimately resulting in the decision to conduct a restoration program; plan and implement the restoration project; and monitor spatial and temporal changes that occurred as a result of the restoration, including the timing for maintenance dredging of shoaling areas that began to restrict tidal circulation. Project implementation by stakeholder groups and resource agencies was prompted by decades of declining habitat and resource values, due to closure of the lagoon mouth to tidal circulation as a result of road and railroad bridge construction. These conditions persisted from at least the early 1980s, resulting in a need to regularly drain impounded freshwater from the lagoon to lessen impacts to the habitats and species. Accordingly, a project was implemented to provide sedimentation control in the eastern (landward) portion of the lagoon, create deeper water areas by dredging, and construct a self-maintaining lagoon mouth. The overall goal was to re-establish and maintain a functional marine estuarine ecosystem.

Benthic resource mapping has been a key tool to document progress towards meeting program goals for a healthy estuary, and provides key data for management decisions on maintenance needs. Spatially geo-referenced mapping tools utilized for the project range from aerial photography to extensive boat surveys of subtidal estuarine habitats and biological resources (e.g., SAV and demersal fish). For example, vegetation mapping for long-term trend analysis utilizes color infrared (CIR) aerial photography (M & A 2002). These ortho-rectified photographic products provide base maps for ongoing field studies, facilitate community and habitat association classification, and allow for spectral analysis of each community to document spatial and temporal changes in acreage (Figure 4.2-1). As exemplified in Figure 4.2-1, shoaling areas indicated by light gray coding in the west part of the Central Basin began to restrict tidal flows (October 2000 panel), and were subsequently dredged to improve circulation (note change in October 2001 panel). These changes are factored into management decisions evaluating the success in fulfilling program goals for enhancement and maintenance of biological resources, particularly changes in key habitats such as eelgrass and the timing of dredging.

Aerial mapping of eelgrass in the lagoon is augmented using side-scan sonar. In other areas of southern and central California, eelgrass mapped by aerial means is regularly under-reported as compared to mapping using sonar methods (M & A 2002). This approach has been refined and applied in San Diego Bay (as noted above), parts of Puget Sound and San Francisco Bay, and in Chesapeake Bay. Original acoustic survey techniques provided useful information for general habitat mapping. However, recent improvements in navigation controls, digital and color readout technology, and increased acoustic frequency, have expanded this capability to map eelgrass and other submerged habitats including algal beds, sand bottom, mud bottom, and hard-bottom features with greater precision and accuracy (Figure 4.2-1; M & A 2002). This level of documentation is critical to identify significant changes in habitats and to balance maintenance and management decisions that can require many months to identify trends, particularly as influenced by seasonal and episodic events (e.g., red tides), and conform with funding cycle specifications and limitations.

A key management goal of the restoration project was to create and enhance eelgrass habitat, as judged by changes in acreage following project implementation (lagoon mouth opening) in December 1996. Some eelgrass recruited naturally to the lagoon, but this was aided by transplantations in October 1997 and August 1998, for a total of 0.25 acres. Habitat mapping to identify areas with fine-grained sediments was integrated with bathymetric data to select transplantation areas. By October 1998, multiple patches of eelgrass had recruited into a central basin and densities reached 0.72 acres. Eelgrass densities continued to increase, reaching approximately 4.46 acres in 1999 and 53.35 acres in 2000 (Figure 4.2-1). Densities decreased slightly to 39.1 acres in 2001 (Figure 4.2-1), apparently influenced by persistent red tide events that reduced water clarity in summer 2000 and resulted in temporary decreases in Batiquitos Lagoon, as evidenced by the figure, and in other San Diego County estuaries (M & A 2002). These results documented the fulfillment of this management goal, combined with mapping data on changes in associated demersal fish communities at numerous permanent transect locations sampled using a variety of trawls and seines (Figure 4.2-2).

Since the restoration project began in late 1996, dredging and lagoon mouth opening have produced a substantial increase in benthic habitat for coastal fishes, corresponding to hundreds of acres out of a total of 650 acres in the estuary. Mapping of fish communities in the lagoon have documented significant increases in the abundance and number of species, including commercially and recreationally important fishes (e.g., California halibut), although abundance is variable among sampling years (M & A 2002; Figure 4.2-2). For example, the number of demersal species increased from 1 species to 27 species, and abundance increased from likely less than 1,000 to peak values of about 18,000 individuals based on sampling at discrete stations. These increases help fulfill a key goal of the restoration, since funding for the project was tied to offsite mitigation for in-filling of harbor habitat (Port of Los Angeles) that impacted fish communities. Overall fish abundance in Batiquitos Lagoon showed distinct seasonal patterns, with the highest numbers in summer (July) and generally lower abundance in winter (January) (Figure 4.2-2). The total number of fishes collected in summer has remained relatively stable since 1997. These seasonal patterns were also observed in species richness and the cumulative number of species collected in the lagoon. The total number of species has steadily increased in all of the habitat guilds, with demersal species having the highest rate of increase. Since April 1998, more structure-associated species (i.e., predominantly associated with eelgrass and algal communities) have been caught compared to the other guilds. This increase represents a fundamental change in the lagoon fish communities and will factor into future management decisions addressing any needs to reduce or minimize further increases in eelgrass by dredging or for use as transplantation source populations.

Long-term challenges for resource management decisions in Batiquitos Lagoon focus on maintenance of tidal flows and estuary depths to counteract episodic sedimentation and in-filling by coastal sand that is transported into the lagoon. On-going mapping of changes in habitats and species abundance enable future correlations of cause and effect relationships, thereby providing key tools for continuing management and maintenance of key resources and appropriate allocation of limited funding.

4.3 Chesapeake Bay

Chesapeake Bay is the largest estuary in the United States, comprising about 7,000 square miles including tidal tributaries, and covering parts of six states (Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia) and the District of Columbia (Figure 4.3-1). The estuary has been subject to substantial environmental degradation and impacts over much of its history, particularly during the past 100 years (USGS 1996; Smith and Greenhawk 1998; Pasternack et al. 2000). Many of these problems have been caused by point and non-point discharges of chemical contaminants and nutrients that affect fisheries, recreational, and aesthetic enjoyment of the estuary. A large, multi-agency and stakeholder coalition has been working for many years to reverse these declining trends, with notable successes in recent years. Key elements for decision-making related to planning, implementation of management programs to help restore and enhance the estuary, and monitoring to document results of these programs, have involved extensive resource mapping to document spatial and temporal patterns and trends. These data have been used as inputs to three principal models, including an estuary model (along with airshed and watershed) that functions as a hydrodynamic and ecosystem model (Boesch 2000). The estuary model is a key underpinning of planning, management, and decision making for the bay, although the biological components of the model have been only partly successful at simulating system responses. Nonetheless, mapping of resource status (e.g., abundance of fishes, invertebrates, and SAV) over many areas of the bay provides an important measure of changes resulting from contaminant source reduction programs.

A key Chesapeake Bay mapping program utilizes Environmental Monitoring and Assessment (EMAP) tools for decision-making and resource management and is organized around the Chesapeake Bay Estuary Model (CBEM) (Linker et al. 2002). Application of the CBEM involves assessing water quality and living resource responses to waste load reductions at many points in the Bay under various management scenarios. As part of the program, a eutrophication model is used to simulate water quality and habitat quality response to nutrient and sediment loads, ultimately related to projected improvements in conditions for biological resources. The process includes simulation of living resource parameters such as dissolved oxygen, where computed values are compared to living resource standards and projections are made of conditions that would benefit key resources of interest, such as oysters and demersal fishes. For example, oyster populations, as represented by harvest data mapped for numerous areas of the bay, have shown recent small improvements after decades of sharp declines (Figure 4.3-2), likely resulting from combined management actions (e.g., contaminant reductions and establishment of sanctuary areas for source populations).

Improving trends have been noted for fish populations such as American shad (*Alosa sapidissima*). A 135-fold increase in the number of shad returning to the Chesapeake Bay Estuary system (Figure 4.3-3) is attributed in part to stocking efforts, a fishing moratorium on this species, and implementation of fish passage aids such as fish ladders around dam complexes and major tributaries. SAV was also a key variable considered in the mapping and decision-making process, since this resource provides important habitat for several species of economic significance and is an important component of the estuarine ecosystem. The Chesapeake Bay SAV data were originally compiled from 1:24,000-scale aerial photography and incorporated into Arc/Info format maps for use as a decision-making tool. Direct simulation of SAV by the CBEM accounted for relationships among eelgrass production, light, and nutrient availability, which allowed for estimates of SAV response to reductions in nutrient and sediment loads. Results from the estuary model, including extensive resource mapping, were used to develop management scenarios that considered potential effects of reduced nutrient and sediment loads on actions needed to enhance or maintain these resources. SAV mapping data since 1984 have shown a progressive increase in this resource (Figure 4.3-4), also potentially related to improvements in water quality (e.g., Figure 4.3-5).

In addition to its extensive monitoring of SAV, the Chesapeake Bay Program has adopted quantitative Benthic Community Restoration Goals that are based on using benthic macroinvertebrate community structure as a reliable and sensitive indicator of habitat quality (Ranasinghe et al. 1994). The restoration goals rely on calculation of the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI), a multi-attribute index that was developed as a means for comparing the relative condition of benthic macroinvertebrate assemblages across different habitat types (Weisberg et al. 1997). In the B-IBI approach, a set of attributes (metrics) that best distinguish between benthic assemblages found at reference sites (i.e., sites relatively free from anthropogenic stress) versus those at degraded sites have been identified and integrated into a single number indicative of habitat health. The B-IBI is scaled from 1 to 5, and sites with values of 3 or more are considered to meet the Benthic Community Restoration Goals. The index is calculated by scoring each of several attributes (e.g., Shannon-Weiner diversity, abundance, biomass, etc.) as either 5, 3, or 1, depending on whether the value of the attribute at a site approximates, deviates slightly from, or deviates strongly from values found at the best reference sites in similar habitats, and then averaging these scores across attributes (Weisberg et al. 1997; Llanso et al. 2002).

The B-IBI has proven useful for addressing a number of different resource management issues within Chesapeake Bay. Dalal et al. (1999) reported on the use of the B-IBI for characterizing baseline conditions in the vicinity of the Poplar Island dredged material placement site, as part of a long-term environmental monitoring program associated with this large-scale habitat restoration project. Adopting a watershed perspective, Dauer et al. (2000) used correlation analysis to examine associations between sites with degraded benthic conditions, as reflected in the B-IBI, and measures of pollution exposure in the water column and sediment related to both human activity (e.g., nutrient loads) and land use patterns (e.g., population density, degree of forestation). Among other findings, a positive relationship was observed between the B-IBI values and forested land use, leading to the authors to suggest that one possible management action to ameliorate the negative effects of deforestation would be to increase the spatial extent of riparian vegetated buffer zones within the Chesapeake Bay watershed (Dauer et al. 2000).

The B-IBI has been used most extensively within the Long-Term Benthic Monitoring and Assessment Component (LTB) of the Maryland Chesapeake Bay Water Quality Monitoring Program (Llanso et al. 2002). This program contains two elements: a fixed site monitoring effort for identifying temporal trends and a probability-based sampling effort to assess the areal extent of degraded benthic community condition. Mapping of long-term trends in B-IBI values at the fixed monitoring sites provides a valuable tool for evaluating the efficacy of management actions aimed at reducing inputs of nutrients and other pollutants, both on a site-specific and system-wide basis (Figure 4.3-6). For example, an improving trend observed in the Chester River in 2001 was potentially linked to a reduction in organic loading, while positive trends in the Elk and lower Potomac Rivers were attributed to overall improvements in water quality parameters including nutrients, chlorophyll and suspended sediments (Llanso et al. 2002).

The LTB's probability-based sampling results have allowed estimates to be made of the spatial extent of degradation, for both Chesapeake Bay as a whole and within individual sub-regions (Figure 4.3-7). In-depth analyses of the B-IBI results from areas failing the Benthic Community Restoration Goals have provided resource managers with valuable insights on the relative importance of different anthropogenic stressors. For example, depauperate benthic communities observed within the Chesapeake Bay mainstem and Potomac River in 2001 were considered indicative of low dissolved oxygen effects, while excess abundance and biomass exhibited by communities in eastern shore tributaries were considered indicative of eutrophic conditions in the absence of low dissolved oxygen stress (Llanso et al. 2002). With better knowledge of the cause(s) of benthic habitat degradation, refinements have recently been made in the development of area-based restoration goals linking water quality to living resources (Llanso et al. 2002).

These case studies exemplify the substantial value of mapping estuarine benthic resources as a key strategy for documenting baseline and spatial-temporal trend data that are needed to fulfill decision-making and environmental management goals.

5.0 DISCUSSION AND CONCLUSIONS

Laws and regulations such as the CWA, CZMA, ESA, and Magnuson-Stevenson Act that encompass estuarine subtidal benthic habitats and resources generally do not specify mapping for purposes of compliance and conformance. However, in response to specific needs by agencies and stakeholders with responsibilities for decision-making and management of key resources, guidelines (e.g., as Southern California Eelgrass Mitigation Policy) and associated mapping to document pre- and post-project effects has evolved as a key tool to fulfill the letter and spirit of these environmental laws. In particular, mapping has been critical to establish baseline conditions for comparison with past or future conditions; develop and document engineering plans and construction results for estuarine habitats (creation, restoration, and enhancement projects); document changes due to natural or human-related effects to evaluate the success of creation, restoration, and enhancement efforts; document the success of mitigation actions and/or compensation required due to project impacts; and/or document the need for management intervention (e.g., to protect a resource from developing or continuing impacts). Permitting and monitoring associated with negotiated agreements (e.g., on-site and off-site mitigation of estuaries for project impacts) are common examples of real-world needs that require mapping for optimal resource management.

Mapping of estuarine benthic resources for many present-day programs utilizes a range of remote (e.g., acoustic and aerial) and discrete (e.g., fixed trawl and benthic grab sampling stations) data collection methods, integrated with precise, geo-referenced navigational (GPS) and display/analysis (GIS) technologies. Application of these methods and use of the resultant data for improving the management of estuarine resources has enabled more informed and defensible decision making, as represented by the case studies described for southern California and Chesapeake Bay.

In particular, the studies for Batiquitos Lagoon and Chesapeake Bay represent resource restoration and management programs, while the San Diego Bay example is primarily focused on resource management. Each study includes remote mapping and display of spatial and temporal trend data on key communities (e.g., eelgrass, fish and benthos) for use in management and decision-making. For Batiquitos and Chesapeake, respectively, these data are used to depict trends related to management actions from restoration of an estuarine ecosystem and reduction of source contaminants to an estuary. In each case, documentation of degraded resource conditions prompted planning and management actions intended to improve resource value, based on increases in the size/amount and quality of the resource. Mapping provided data to judge the success of these actions, as evidenced by substantial increases in plant communities in Batiquitos Lagoon, increases in fishes in Batiquitos and Chesapeake, and improvements in the condition of Chesapeake Bay benthic communities, evidently in response to the restoration program and contaminant reductions. In association with the expansion of the plant communities, substantial increases in the abundance and diversity of fish communities were directly evident from mapping trend data for Batiquitos, along with healthier benthic invertebrate communities in Chesapeake Bay, to improvements in environmental quality and management actions. Use of mapping to document trends in action-response variables for benthic resources enables informed decisions via periodic, results-oriented feedback loops. This process has directly improved management and decision-making, including allocation of limited funding resources, in both estuaries. Similar feedback loops have enabled effective management of eelgrass and fish community resources in San Diego Bay, based on maintenance of mitigation banks to offset impacts from generally small-scale projects. This type of planning and management promotes responsible stewardship in the balance of development and protection of estuarine benthic resources, including consideration of cumulative impacts.

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Table 1.
Principal Laws/Regulations and Agency Guideline Examples Related to Subtidal Estuarine Resources

LAWS/REGULATIONS	**RESOURCES**
Clean Water Act	Waters of the U.S. and beneficial uses
Coastal Zone Management Act	Species, habitats, and beneficial uses
Endangered Species Act	Listed fish, invertebrates, birds, plants, and designated critical habitats
Magnuson-Stevenson Act	Essential Fish Habitat (e.g., eelgrass beds, kelp forests, estuaries, and spawning areas)
GUIDELINE EXAMPLES	
Southern California Eelgrass Mitigation Policy (NMFS)	Essential Fish Habitat
Least Tern MOU (USFWS and U.S. Navy)	ESA-listed bird species

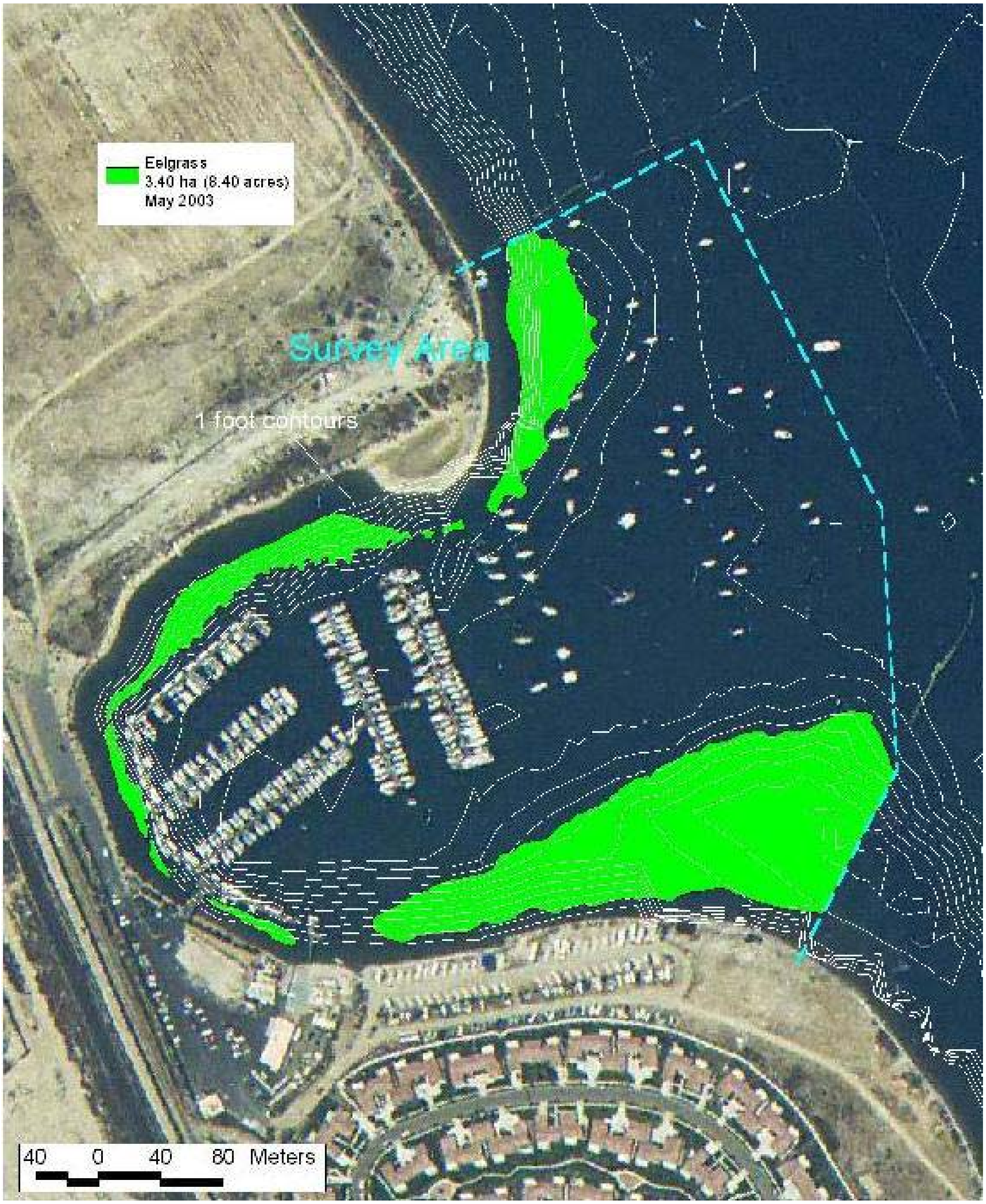

Figure 4.1-1 Example of Benthic Habitat Mapping of Eelgrass Habitats in San Diego Bay, CA, for U.S. Navy Environmental Project

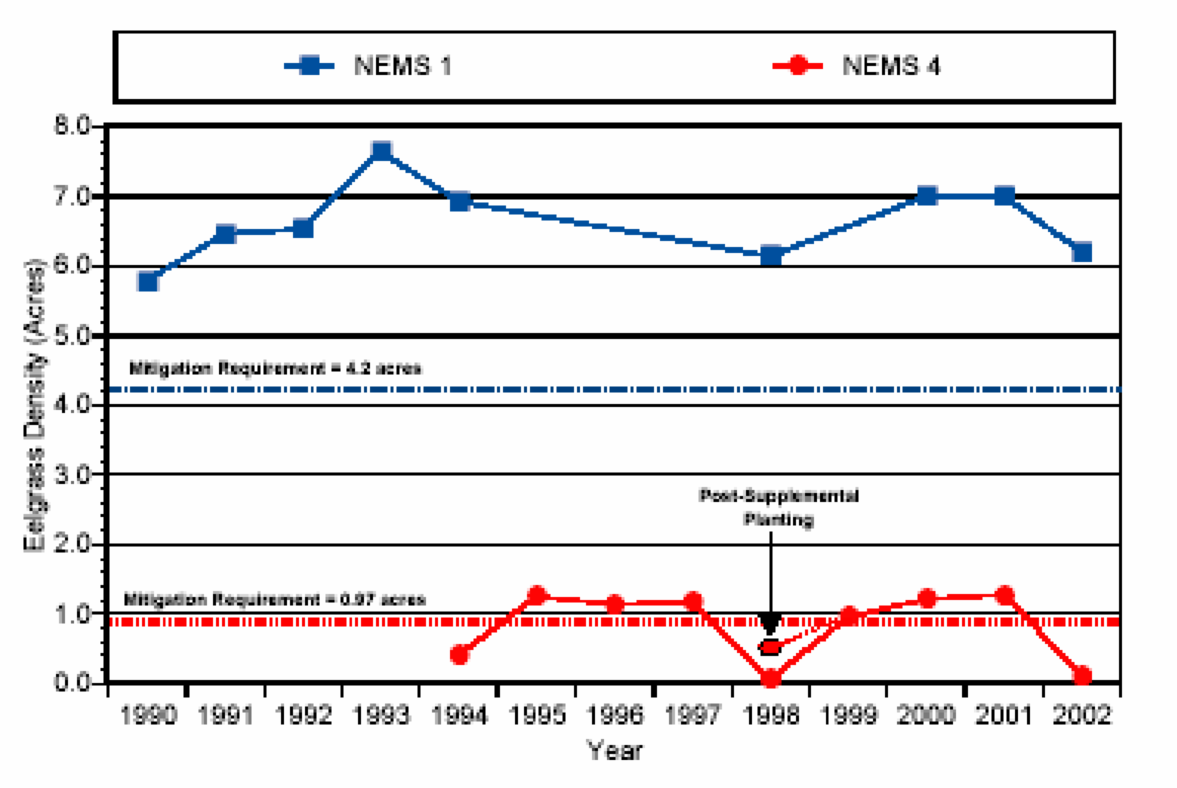

Figure 4.1-2 Changes in Eelgrass Density at Navy-Developed Eelgrass Mitigation Sites (NEMS) in San Diego, CA

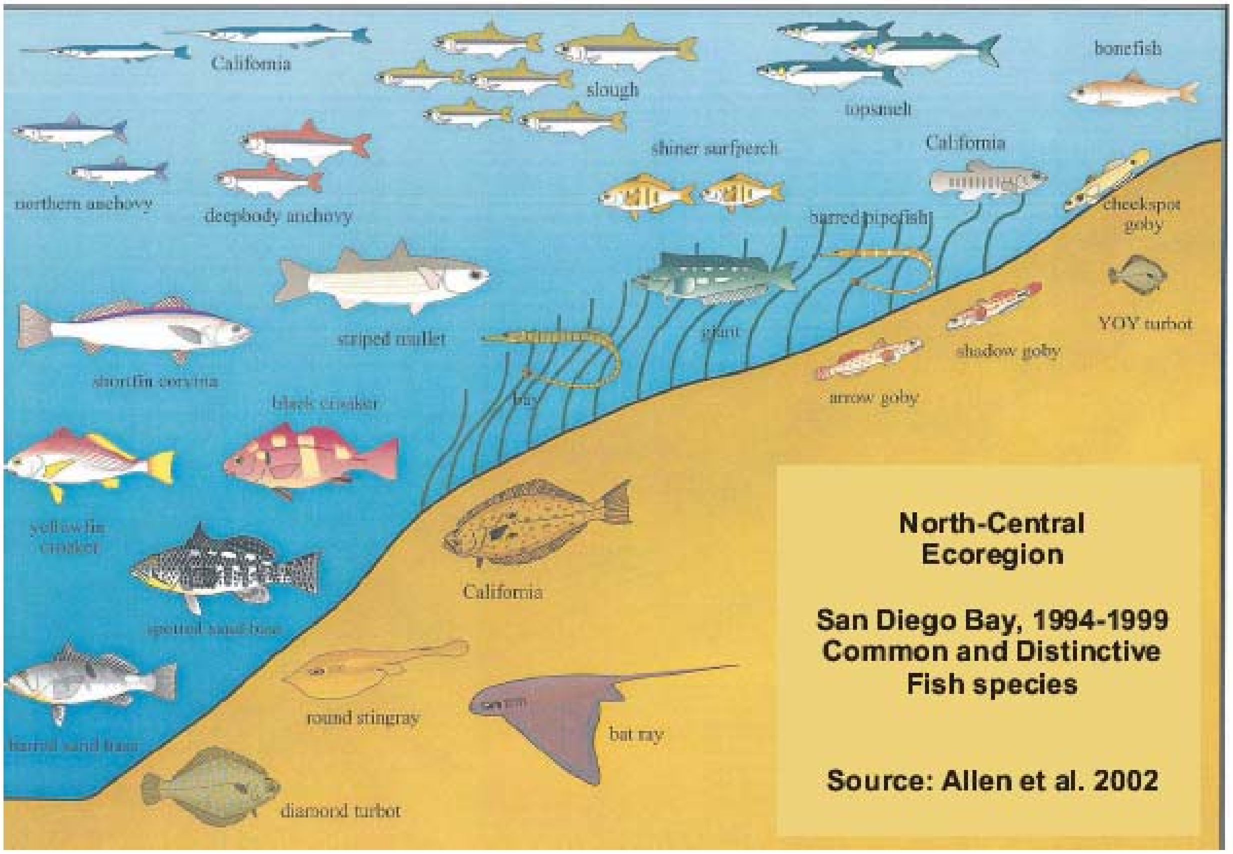

Figure 4.1-3 Fish Communities Typical of Eelgrass Beds in San Diego Bay, CA

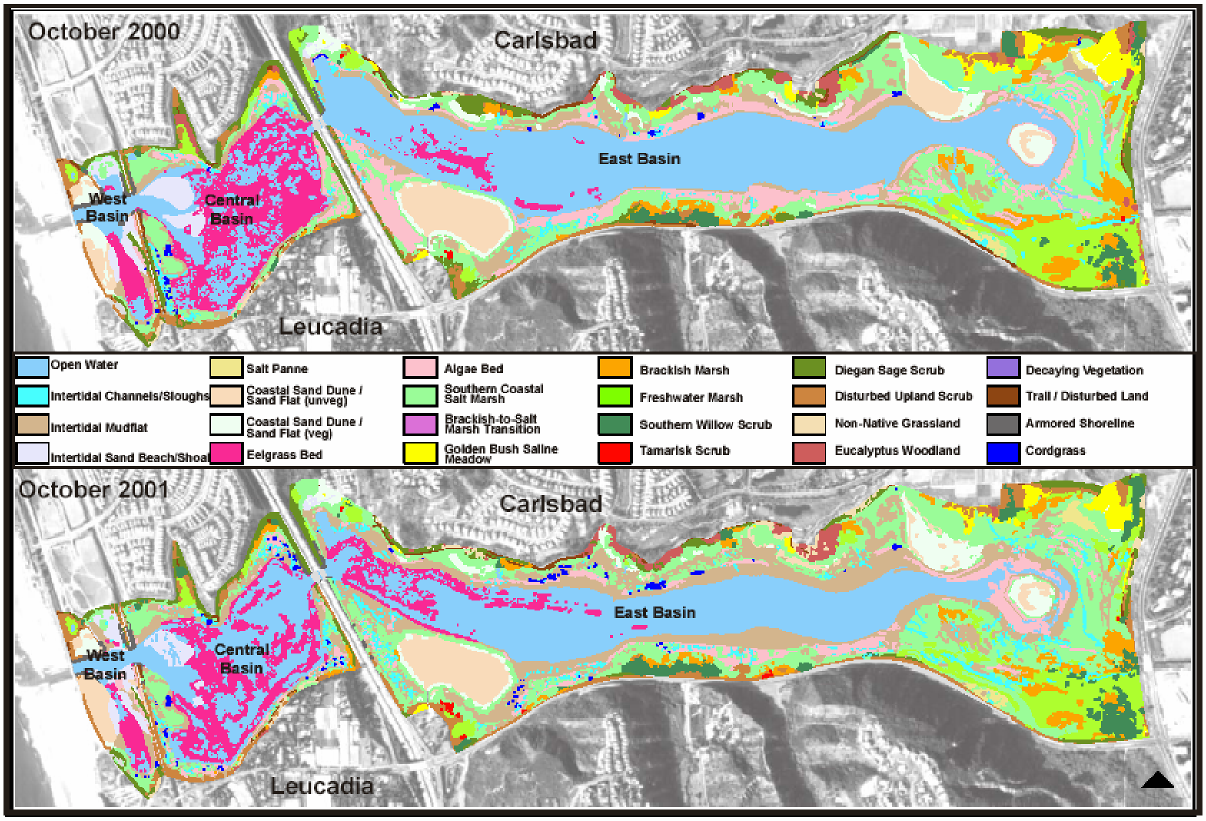

Figure 4.2-1 Habitat Components of Batiquitos Lagoon for October 2000 and 2001 Based on Analysis of Aerial Photographs Augmented by Side-scan Sonar Surveys

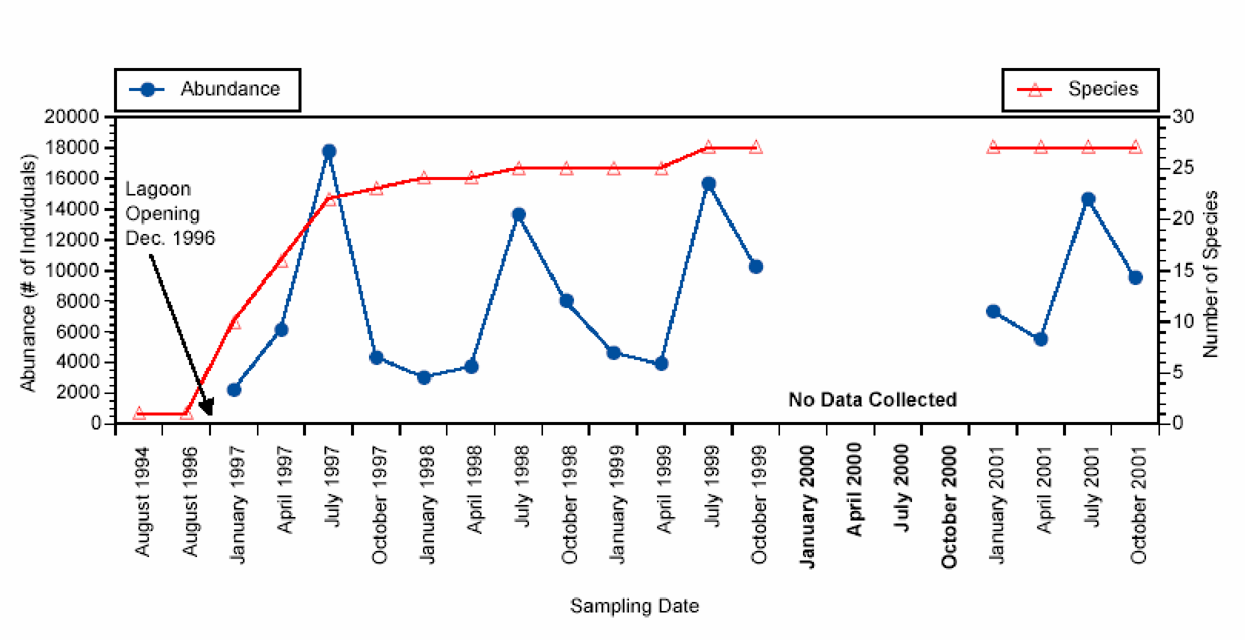

Figure 4.2-2 Temporal Trends in Demersal Fish Abundance and Species at Batiquitos Lagoon, Carlsbad, CA

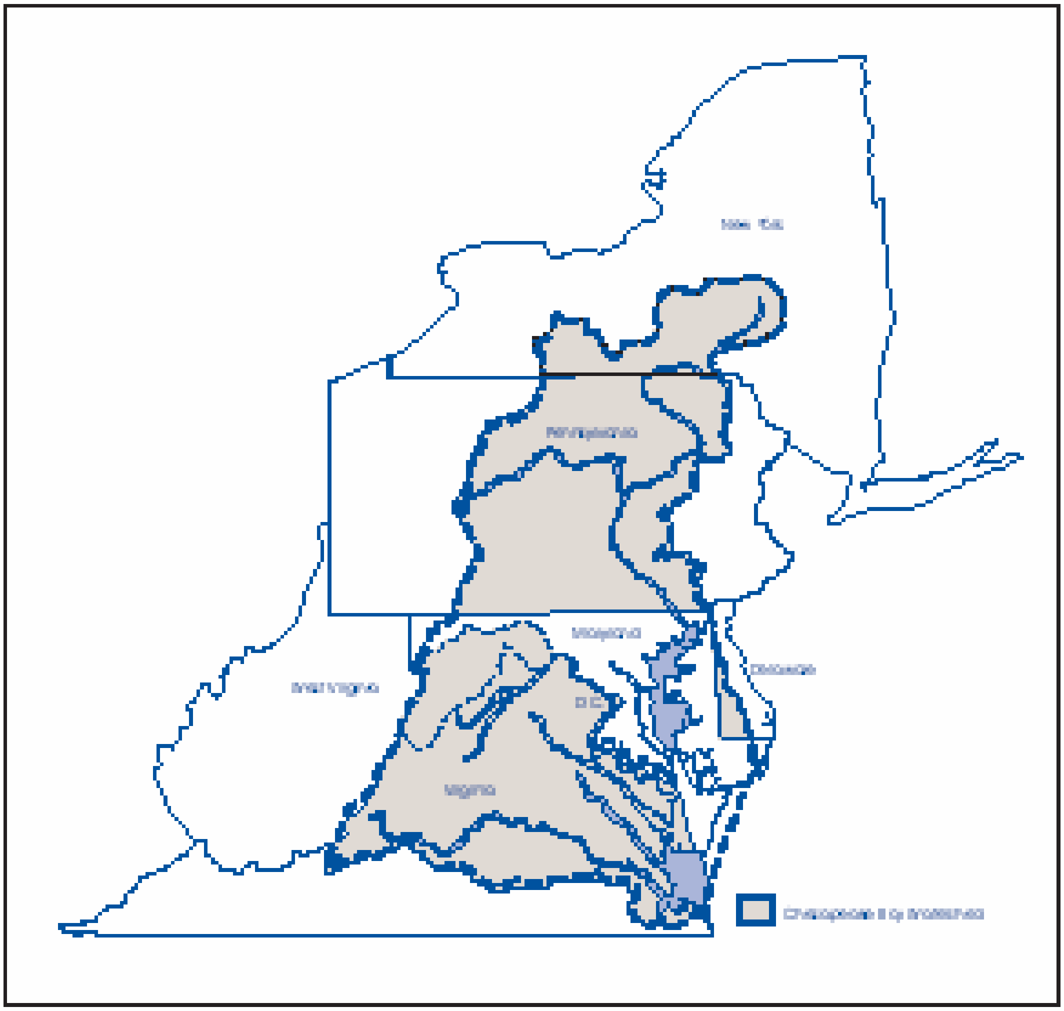

Figure 4.3-1 Location of Chesapeake Bay Watershed

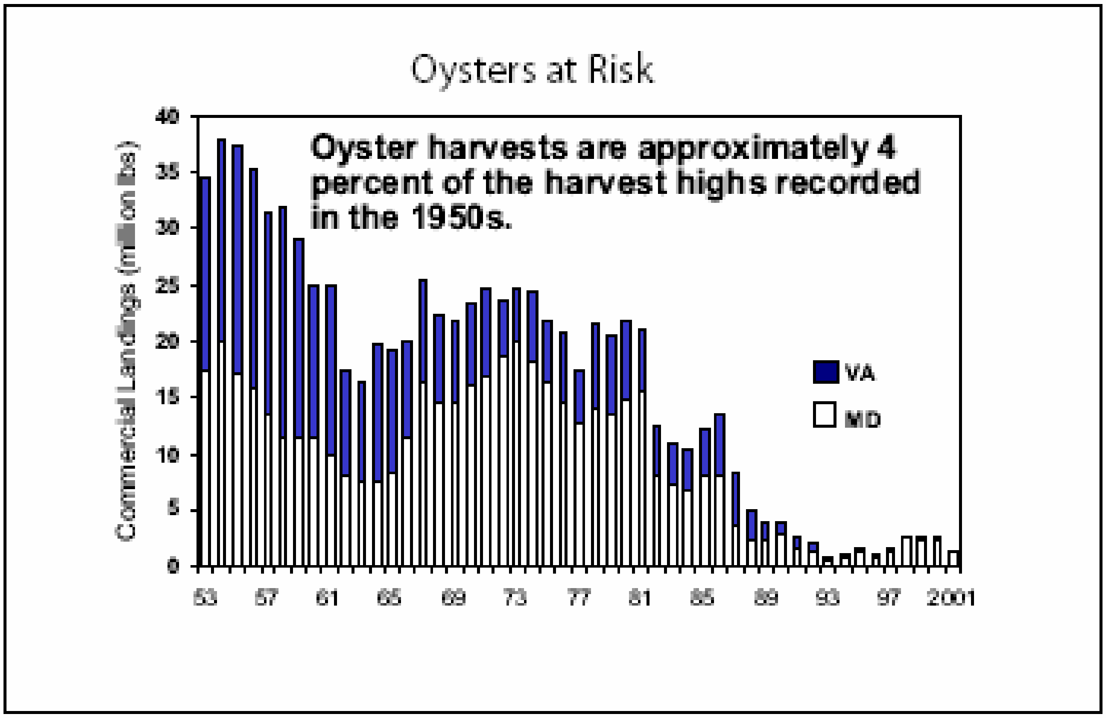

Figure 4.3-2 Temporal Trends in Oyster Harvests in Chesapeake Bay

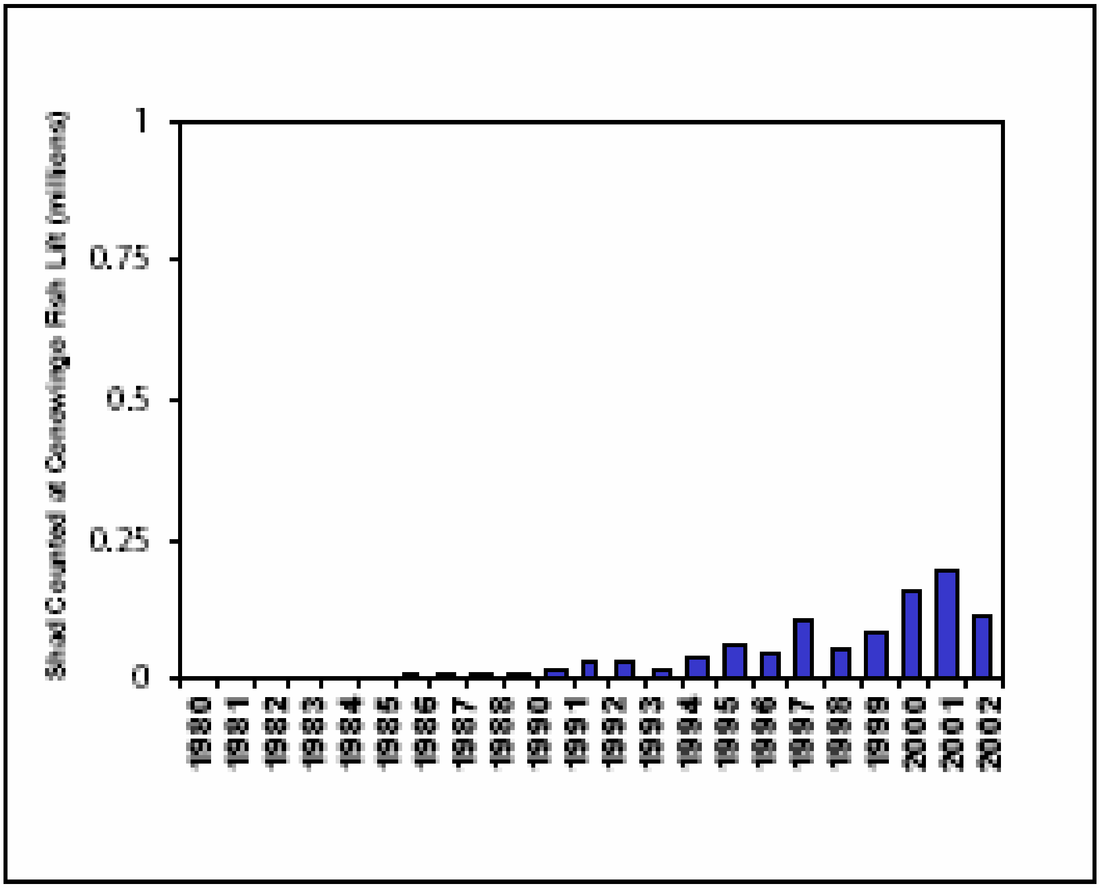

Figure 4.3-3 Temporal Trends in Fish Abundance (American Shad) in Chesapeake Bay

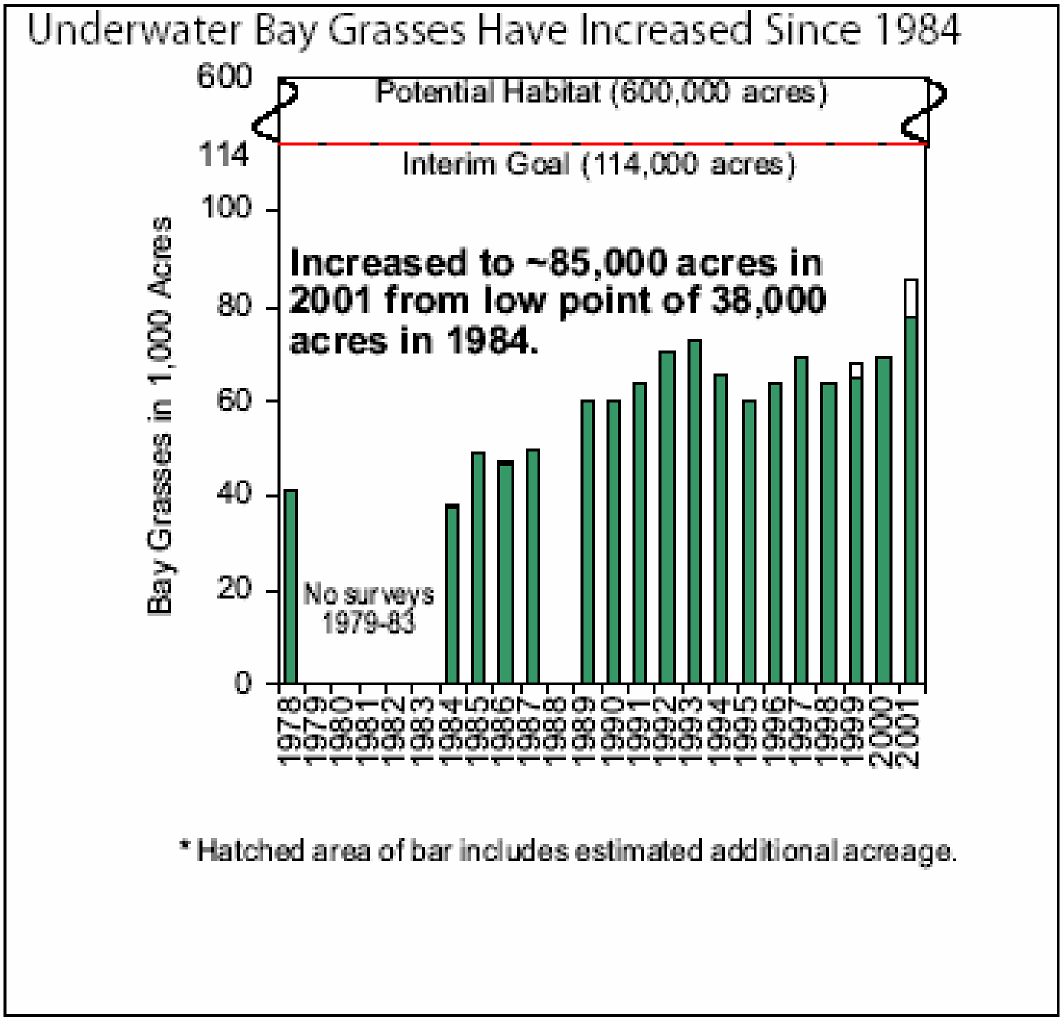

Figure 4.3-4 Temporal Trends in Submerged Aquatic Vegetation (SAV; Bay Grasses)

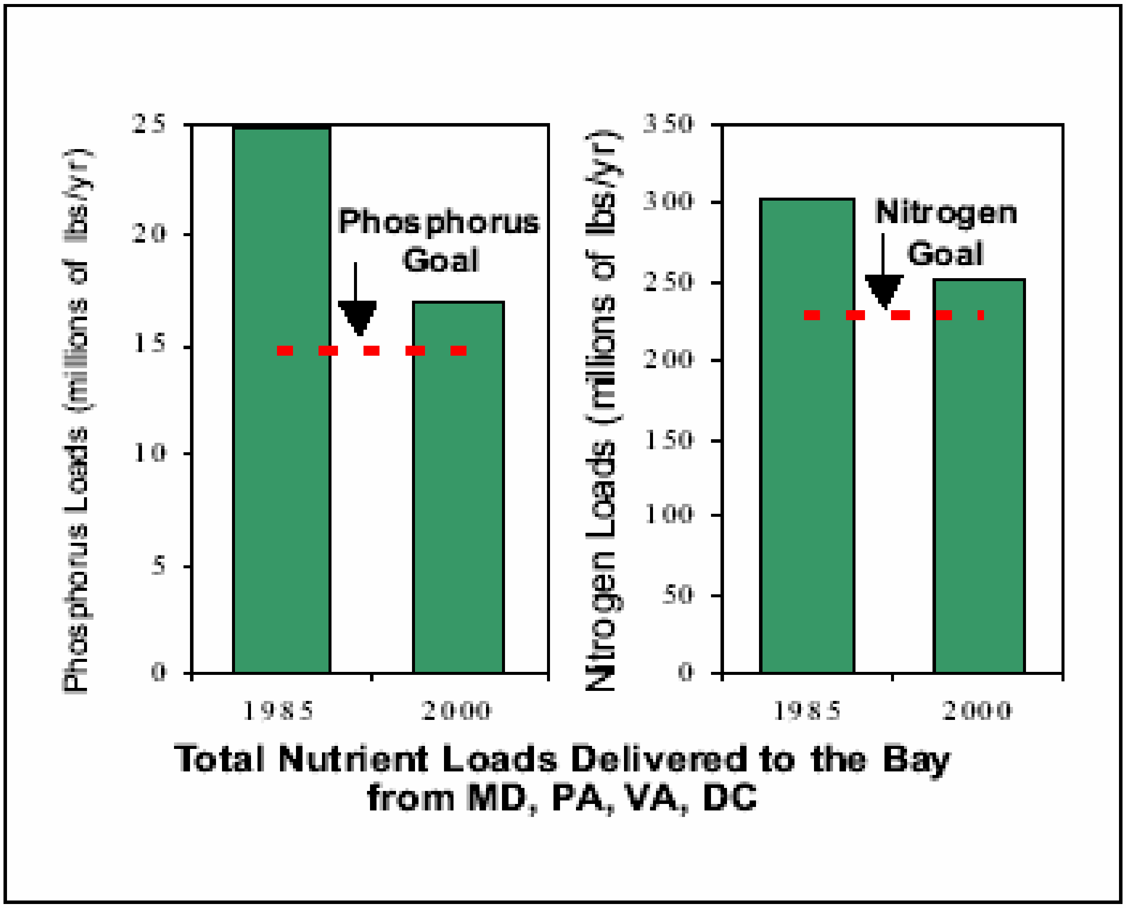

Figure 4.3-5 Temporal Changes in Nutrient Loads to Chesapeake Bay

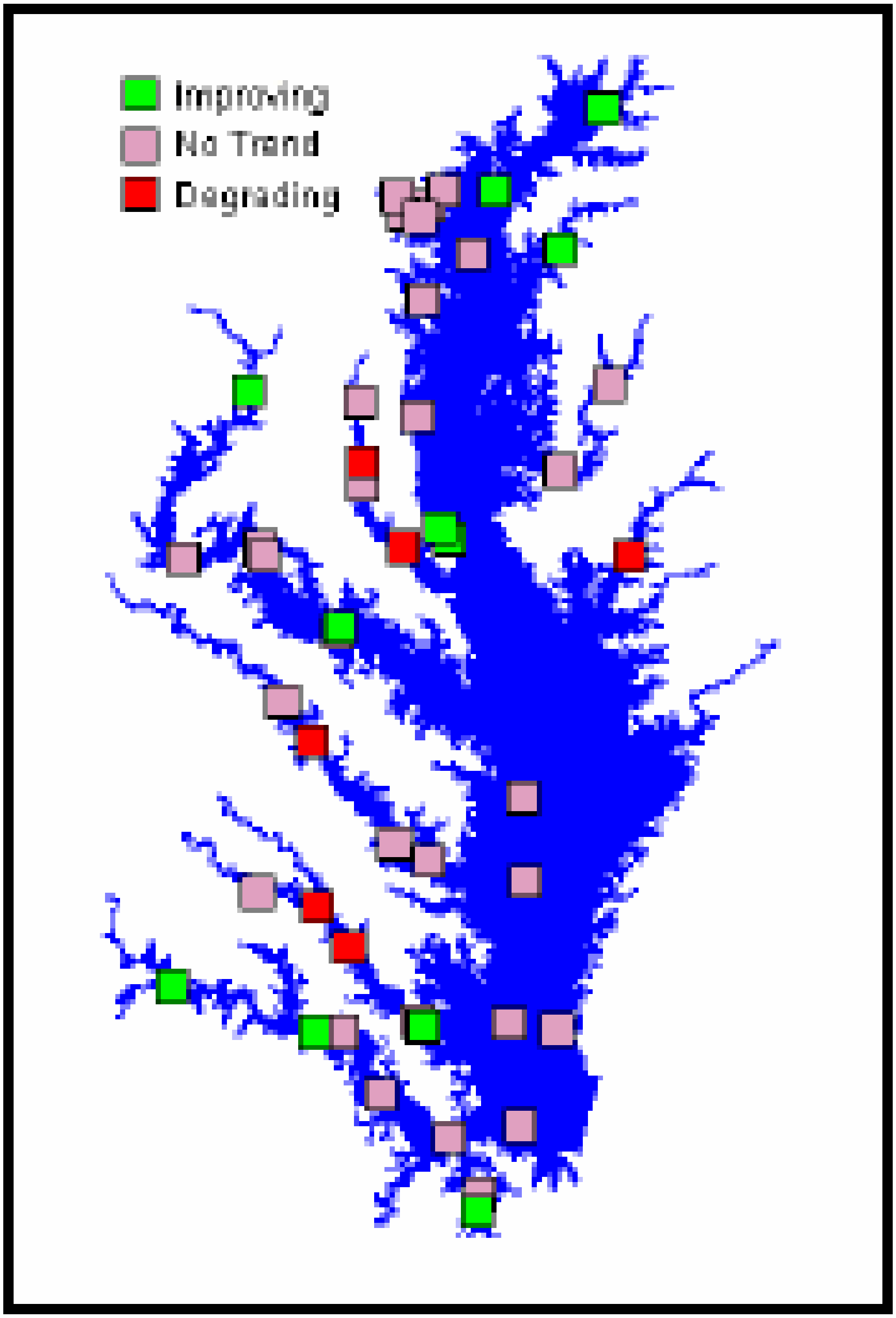

Figure 4.3-6 Trends in the condition of benthic communities in Chesapeake Bay (Maryland Portion) between 1985 and 2001 based on the Benthic Index of Biotic Integrity (B-IBI). From: http://www.baybenthos.versar.com/.

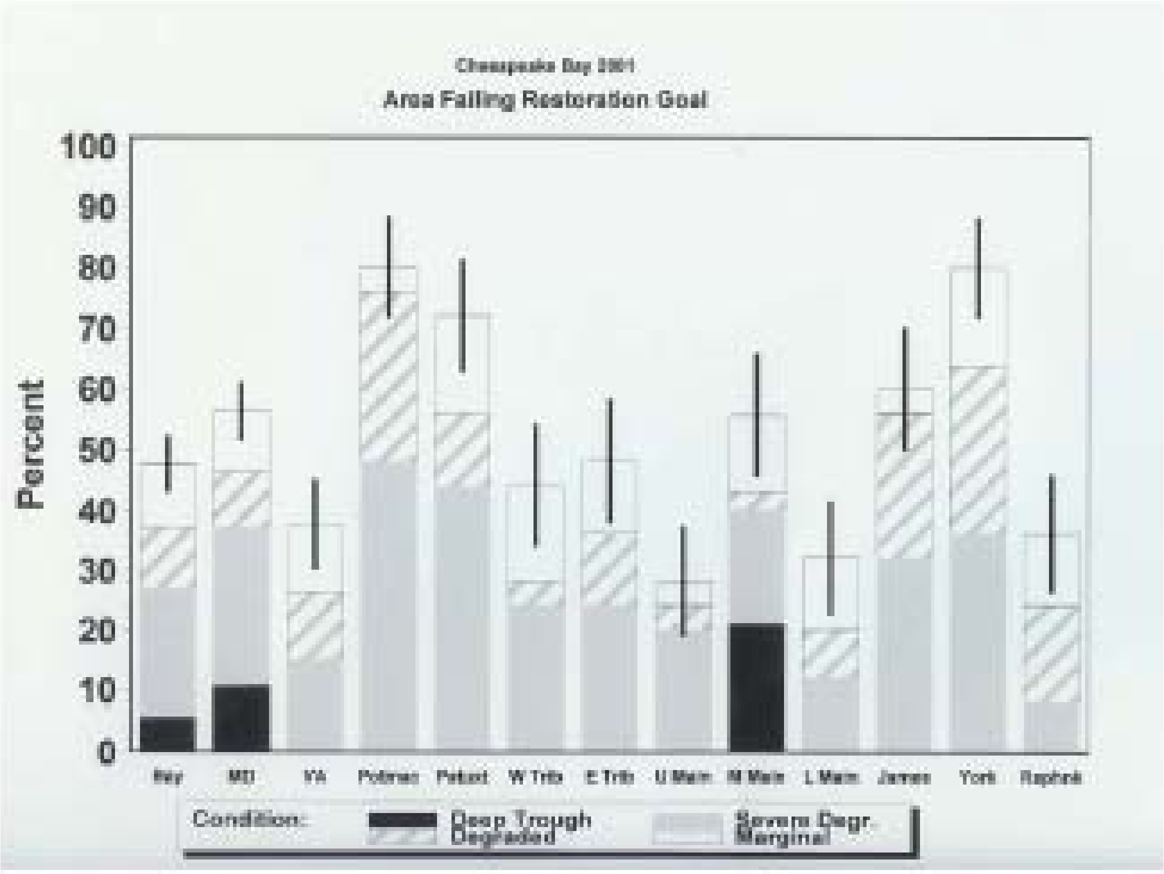

Figure 4.3-7 Proportion of the Chesapeake Bay, Maryland, Virginia, and various sub-regions failing the Chesapeake Bay Benthic Community Restoration Goals in 2001 (from Llanso et al. 2002).