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Monitoring Seagrass Distribution and Abundance Patterns: A Case Study from the Chesapeake Bay

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Contents

Page

Preface

This report was prepared by the National Ocean Pollution Policy Board's Habitat Loss and Modification Working Group, which is an interagency technical committee established by the National Ocean Pollution Policy Board pursuant to recommendations contained in the current *National Marine Pollution Program Federal Plan for Ocean Pollution Research, Development, and Monitoring: Fiscal Years 1988–1992* (Federal Plan). The working group is jointly chaired by the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service and the U.S. Department of the Interior's Fish and Wildlife Service. The activities of the working group are coordinated through NOAA's National Ocean Pollution Program Office, which also directed preparation of the Federal Plan.

Understanding the effects of losing or modifying marine habitats as a result of human activities is one of six goals identified in the Federal Plan. The working group was charged with undertaking projects that would address recommendations outlined in the Federal Plan for achieving this goal at the Federal level, and to arrive at products that would be useful for Federal agencies planning and conducting habitat programs. Three study areas were selected: coastal wetlands mapping, coastal habitat loss, and wetland mitigation.

Examining the Federal effort in mapping the Nation's coastal wetlands was selected as the initial project because determining the current areal extent of these wetlands is fundamental to determining the actual rates and locations of loss. For this project, a workshop was conducted that included persons representing federally funded coastal wetlands mapping programs. The workshop took place in December 1989 at the U.S. Fish and Wildlife Service's National Wetlands Research Center in Slidell, Louisiana. The papers presented at the workshop are contained in this report. They are preceded by an overview of the major federally funded programs and the working group's conclusions and recommendations as to how the overall Federal effort in coastal wetlands mapping could be improved so that the status and trends of the Nation's coastal wetlands are documented in a timely fashion.

Monitoring Seagrass Distribution and Abundance Patterns: A Case Study from the Chesapeake Bay[1]

by

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ABSTRACT.—Seagrasses, or submerged aquatic vegetation (SAV), have been mapped in the Chesapeake Bay five times between 1978 and 1987 with standard aerial photographic techniques, resulting in annual reports on SAV distribution. Acquisition of the vertical photography at a scale of 1:24,000, adhering to strict quality-assurance guidelines based on sun angle, tidal stage, cloud cover, wind speed, and season, has produced excellent, high-contrast imagery delineating beds of SAV from adjacent, unvegetated areas. Ground-truthing data from various State, Federal, and public organizations have corroborated the photographic data base. Digitized bed outlines resulting from photointerpretation of the imagery onto 1:24,000-U.S. Geological Survey topographic quadrangles have been stored on a Virginia Institute of Marine Science geographic information system (GIS). A report summarizing the photographic and ground survey data is produced each year. Results from these surveys have shown distinct changes in the distribution and abundance of SAV in different areas in the bay over the last 10 years. The amount of SAV has increased 21% from 1978 to 1987 with some areas showing rapid increases in less than 5 years. The success of these annual surveys in the Chesapeake Bay indicates that aerial photographic techniques can be used to delineate spatial and temporal patterns of seagrass communities, as well as those communities comprised of brackish-water species. Appropriate GIS systems can be employed to assess historical trends at any location.

Seagrasses are submersed vascular plants found in shallow-water coastal and estuarine environments throughout the world. There are about 50 species growing in a wide variety of sediments from the intertidal zone to depths of 10 m. In turbid estuarine environments, such as the Chesapeake Bay, seagrasses are not found at depths below 2 m at mean low water (MLW), whereas in less turbid areas, such as the Caribbean Sea, seagrasses can be found at depths of 50 m or more.

Seagrasses, like their emergent wetland counterparts, serve many different functions. Because they baffle currents and stabilize sediments, extensive seagrass beds adjacent to shorelines can reduce shoreline erosion. Seagrass beds support dense assemblages of vertebrates and invertebrates and often serve as nursery areas for many commercially important species, such as the bay scallop, *Aequipectin irradians*. Seagrass meadows are important in nutrient cycling between sediments and the overlying water, and they contribute to the detrital food chain. Only a few groups of animals (e.g., geese, dugongs, manatees) actually consume seagrassses; however, the attached epiphytes are food for invertebrates (e.g., gastropods, amphipods), which in turn are food for secondary consumers.

In the continental United States, seagrasses are present in every coastal State except Delaware, Georgia, and South Carolina, although quantitative estimates on distribution and abundance in many States are generally lacking. Table 1 presents a summary of data currently available on the abundance of seagrasses as compared with total area of salt marsh. Seagrass coverage in many

[1] Contribution No. 1576 from the Virginia Institute of Marine Science, Gloucester Point, Virginia 23062.

Table 1. *Salt marsh and seagrass coverage (hectares) by State[a] (modified from Orth and van Montfrans 1990). No data are available for seagrasses in those coastal States not listed.*

State	Salt marsh (reference[b])	Seagrass (reference[b])
New York	10,810 [1]	78,100 [10]
New Jersey	83,989 [2]	12,624 [1,11]
Delaware	26,183 [3]	0
Virginia–Maryland	145,813 [3,4]	17,353 [12]
North Carolina	64,291 [1]	80,972 [13]
South Carolina	149,580 [5]	0
Georgia	151,538 [1]	0
Florida–Atlantic Coast	38,826 [1]	2,800 [14]
Florida–Gulf Coast	137,455 [6,7c]	913,700 [14]
Alabama	11,855 [8]	12,300 [14]
Mississippi	24,919 [9]	2,000 [14]
Louisiana	720,648 [9]	4,100 [14]
Texas	174,899 [6]	68,500 [14]

[a] Wetland areas identified as containing salt-tolerant vegetation (categorized as "salt marsh" or "nonfresh" in data reports or published papers) were used and listed in the totals above.
[b] 1, Field et al. 1988; 2, Tiner 1985a; 3, Tiner 1985b; 4, Silberhorn, Virginia Institute of Marine Science, personal communication; 5, Tiner 1977; 6, Reyer et al. 1988; 7, Perry 1984; 8, Roach et al. 1987; 9, E. C. Pendleton, U.S. Fish and Wildlife Service, personal communication; 10, Macomber and Allen 1979; 11, Dennison, et al. In press; 12, Orth et al. 1989; 13, Ferguson et al. 1988; 14, Iverson and Bittaker 1986.
[c] Includes 34,540 ha of mangroves listed in Perry 1984.

States may be underestimated because of the lack of quantitative mapping studies. Seagrass monitoring programs are rare because of the inherent technical difficulties and cost in censusing these underwater populations (Orth and Moore 1983a). Some seagrass beds have been mapped successfully with remote-sensing techniques such as low-level or satellite photography, or through field surveys including transects or randomized sampling (Orth and Moore 1983a; Walker 1989). However, most State and Federal agencies have focused their efforts on emergent wetlands. The U.S. Fish and Wildlife Service's National Wetlands Inventory is one such mapping effort.

In recent decades, seagrass declines have occurred worldwide (Kemp et al. 1983; Orth and Moore 1983b; Cambridge and McComb 1984; Neverauskas 1987). The magnitude of these losses, in many cases, has been difficult to assess because of inadequate data on distribution and abundance patterns before the decline. Monitoring seagrass distribution and abundance is critical for making quantitative assessments of losses, thereby increasing our understanding of factors controlling growth and distribution.

Development of a Seagrass Monitoring Program: A Case Study of Chesapeake Bay

A decline of seagrass and brackish-water species throughout Chesapeake Bay in the late 1960's and 1970's (Kemp et al. 1983; Orth and Moore 1983b, 1984) led the U.S. Environmental Protection Agency to initiate a major research program in 1978. This program determined the distribution and abundance of submersed bay grasses and the factors that contributed to their decline. The greatest loss of vegetation occurred in the upper and middle sections of the bay and tributaries (Fig. 1). The results of the studies indicated that nutrient enrichment and high levels of turbidity were associated with the declines in a number of areas (Kemp et al. 1983).

A 1987 agreement signed by the governors of Maryland, Pennsylvania, and Virginia, and the mayor of Washington, D.C., committed the States to develop management policies for the living resources of the bay. A committee of Federal, State, and university scientists and managers developed a management policy to protect, enhance, and restore seagrass and brackish-water species (collectively referred to as submerged aquatic vegetation or SAV) in the bay. This policy was approved and signed in July 1989. An implementation plan for the SAV management policy is being developed by the committee.

Surveys of SAV and brackish-water species have revealed several large changes in distribution and abundance over a short time. Therefore, one requirement of the SAV management policy is to develop a monitoring program that will annually determine the distribution and abundance of SAV. This program will be implemented by using low-level, vertical aerial photographs and ground surveys. This survey methodology was developed over a 10-year period in Chesapeake Bay. In aerial photographs, seagrasses—under appropriate environmental conditions—generally have a signature distinct from adjacent, unvegetated areas. Aerial photographs also provide a synoptic view of baywide patterns for future analysis. The first baywide survey to use low-level, vertical aerial

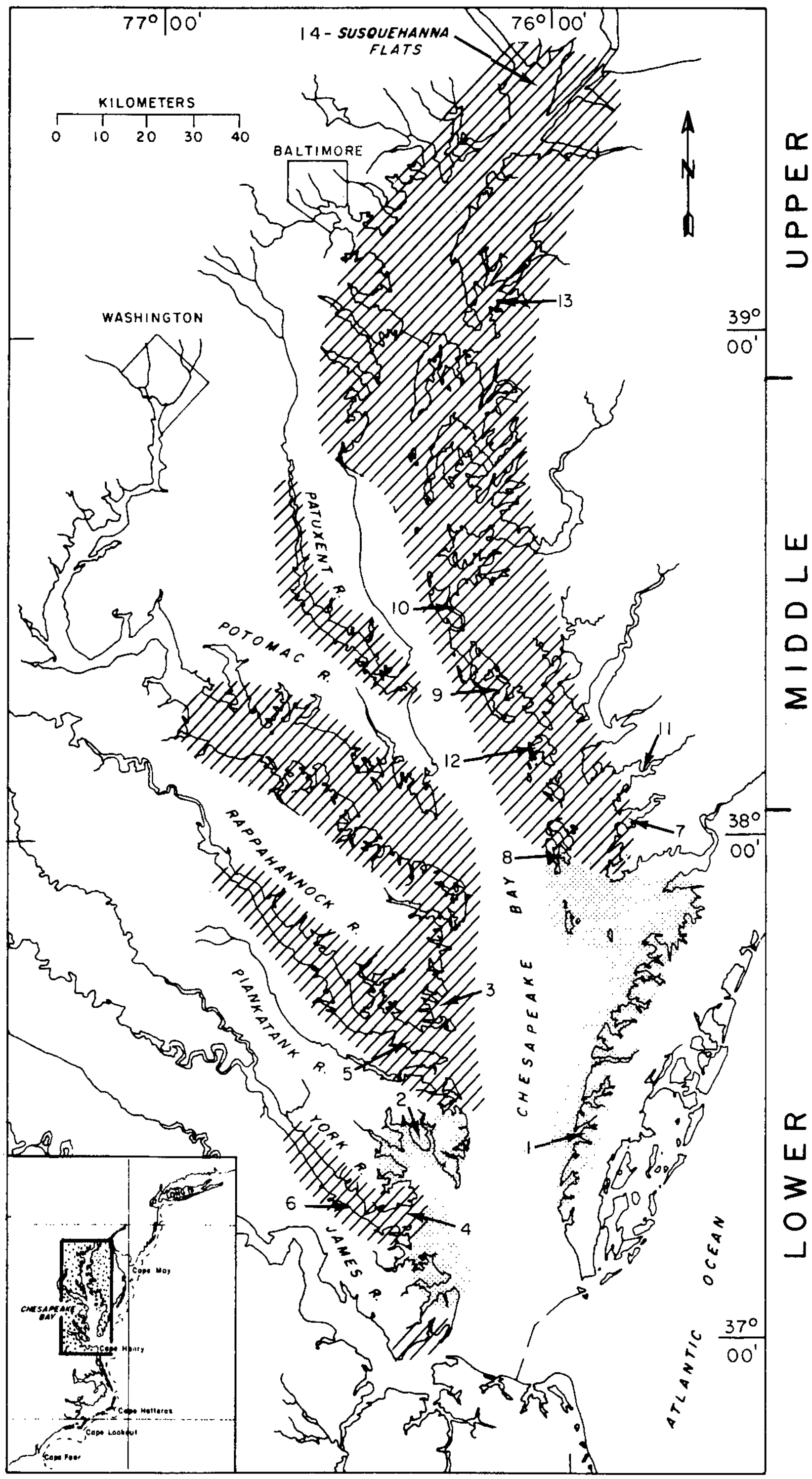

Fig. 1. Chesapeake Bay and tributaries showing major declines of submerged aquatic vegetation (SAV; crosshatched area) during the 1960's and 1970's, and showing areas where SAV was still abundant (stippled area; reprinted with permission of Science; see Orth and Moore 1983b).

photography was conducted in 1978 (Orth et al. 1979; Anderson and Macomber 1980). Subsequent baywide surveys were conducted in 1984–87 and 1989 with the same methodology (Orth et al. 1985, 1986, 1987, 1989). Additional aerial surveys were conducted in the lower bay in 1974, 1980, and 1981, and historical aerial photographs were used to map the lower western shore in 1971 (Orth and Gordon 1975).

Submerged Aquatic Vegetation Species

Ten SAV species are commonly found in the Chesapeake Bay and its tributaries. The limits of a species' distribution are determined by its salinity tolerance (Orth and Moore 1981). *Zostera marina* (eelgrass), tolerant of salinities as low as 10 o/oo, is abundant in the lower portion of the bay. *Myriophyllum spicatum* (water milfoil), *Potamogeton pectinatus* (sago pondweed), *Potamogeton perfoliatus* (redhead grass), *Zannichellia palustris* (horned pondweed), *Elodea canadensis* (common elodea), *Ceratophyllum demersum* (coontail), *Najas guadalupensis* (southern naiad), and *Vallisneria americana* (wild celery) are less tolerant of high salinities and are found in the middle and upper sections of the bay and tributaries. *Ruppia maritima* (widgeon grass) is tolerant of a wide range of salinities and is found throughout the bay. About 11 other species are occasionally found in the middle and upper reaches of the bay and tidal rivers (Table 2). *Hydrilla verticillata* (hydrilla) was introduced into the Potomac River in 1981 and rapidly became abundant in the tidal freshwater section.

Aerial Photography and Ground Truthing

SAV photographs are obtained by using standard aerial mapping cameras, with either black and white or color film (both film types have been used effectively in the monitoring program). Photographs are taken at an altitude of about 12,000 feet, yielding a 1:24,000 photographic scale. Coverage includes all areas known to have SAV and areas that could potentially support SAV (i.e.,

Table 2. *Species of submerged aquatic plants found in Chesapeake Bay and tributaries (from Orth et al. 1989).*

Family	Species	Common name
Characeae (muskgrass)	*Chara braunii*	Muskgrass
	Chara zeylanica	
	Nitella flexilis	
Potamogetonaceae (pondweed)	*Potamogeton perfoliatus bupleuroides*	Redhead grass
	Potamogeton pectinatus	Sago pondweed
	Potamogeton crispus	Curly pondweed
	Potamogeton pusillus	Slender pondweed
	Ruppia maritima	Widgeon grass
	Zannichellia palustris	Horned pondweed
	Zostera marina	Eelgrass
Najadaceae	*Najas guadalupensis*	Southern naiad
	Najas gracillima	Naiad
	Najas minor	Naiad
Hydrocharitaceae (frogbit)	*Vallisneria americana*	Wild celery
	Elodea canadensis	Common elodea
	Egeria densa	Water-weed
	Hydrilla verticillata	Hydrilla
Pontedariaceae (pickerelweed)	*Heteranthera dubia* (= *Zosterell dubia*)	Water stargrass
Ceratophyllaceae (coontail)	*Ceratophyllum demersum*	Coontail
Trapaceae	*Trapa natans*	Water chestnut
Haloragaceae (water milfoil)	*Myriophyllum spicatum*	Eurasian water milfoil

generally all areas where water depths are less than 2 m at MLW), as well as land control points.

Survey flight lines are prioritized by area and are flown when the standing crop for the dominant species is at its peak. General guidelines governing mission planning and execution have been established; these guidelines address tidal stage, plant growth, turbidity, sun elevation, wind, water and atmospheric transparency, sensor operation, and plotting (Table 3). These guidelines ensure that photographs will be obtained during optimal conditions for detecting SAV, thus aiding accurate photointerpretation.

Field surveys of SAV communities are done by a number of State and Federal agencies and persons in Maryland and Virginia, including the U.S. Geological Survey (USGS), Maryland Department of Natural Resources, and Chesapeake Bay Foundation. Some surveys are conducted independent of the aerial mapping program; these include those surveys associated with SAV restoration programs in Maryland and Virginia, whereas other surveys support the aerial survey by checking SAV beds that were mapped the previous year. All data are synthesized in a report of the annual mapping program.

Table 3. *Guidelines followed during acquisition of aerial photographs.*

Tidal stage—Photography is acquired at low tide, ± 0–1.5 feet, depending on overall water clarity and tidal regime of the area, as predicted by the National Ocean Survey tables.

Plant growth—Growth stages must ensure maximum delineation of SAV, and when phenologic stage overlap should be greatest.

Sun angle—Surface reflection from sun glint must not cover more than 30% of frame. Sun angle should be between 20° and 40° to minimize water surface glitter. At least 60% line overlap and 20% side lap are used to minimize image degradation due to sun glint.

Turbidity—Clarity of water must ensure complete delineation of grass beds. This is visually determined from the airplane to ensure that SAV could be seen by the observer.

Wind—Photography is acquired during periods of no wind or low wind. Offshore winds are preferred over onshore winds when wind conditions cannot be avoided.

Atmospherics—Photography is acquired during periods of no haze or low haze or clouds below aircraft. There should be no more than scattered or thin broken clouds, or thin overcast above aircraft, to ensure maximum SAV-to-bottom contrast.

Sensor operation—Photography is acquired in the vertical mode with 5° tilt. Scale/altitude/film/focal length combination must permit resolution and identification of about 1 m^2 area of SAV (surface).

Plotting—Each flight line includes sufficient identifiable land area to ensure accurate plotting of grass beds.

Mapping Process

The USGS's 7.5-min topographic quadrangles are used as a basis for mapping SAV beds from aerial photography, digitizing SAV beds, and compiling SAV bed-area measurements (Fig. 2). Photointerpretation of SAV beds requires all available information, including knowledge of distinct aquatic grass signatures on film, ground surveys, and low-level aerial reconnaissance surveys. Delineation of boundaries of SAV beds onto topographic quadrangles is done by superimposing the appropriate mylar quadrangle onto the appropriate photograph. A best fit is obtained where minor scale differences are evident between the photograph and the mylar quadrangle. Shoreline changes are noted on the quadrangle if significant shoreline erosion or accretion has occurred since USGS publication of a map.

In addition to delineating the boundaries of the SAV bed, the percent of cover within each bed is estimated by using an enlarged crown-density scale similar to that developed for estimating forest crown cover. Bed density is classified into one of four categories based on a subjective comparison with the density scale. Either the entire bed, or subsections within the bed, are assigned a number (1 = very sparse or <10% coverage; 2 = sparse or 10–40% coverage; 3 = moderate or 40–70% coverage; 4 = dense or 70–100% coverage) corresponding to the density categories. Additionally, each distinct SAV unit is assigned a two-letter designation unique to the map. Subsections of beds are further identified as being part of a contiguous bed by the addition of a code unique to that bed.

SAV Perimeter Digitization and Area Calculation

The perimeters of all SAV beds mapped from aerial photographs are digitized using a Numonics

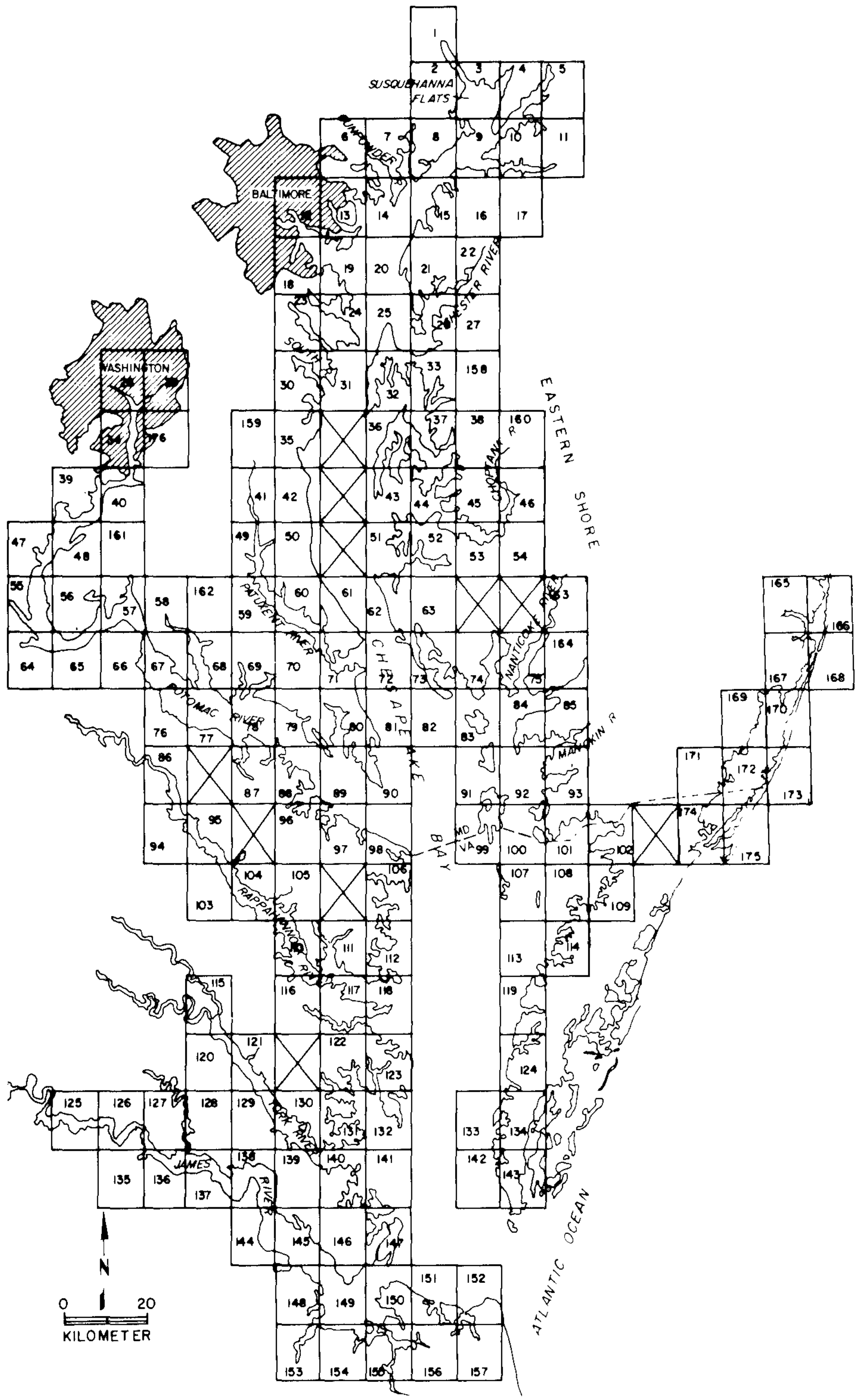

Fig. 2. Chesapeake Bay—locations of topographic quadrangles used in submerged aquatic vegetation monitoring program.

Model 2400/2200 Digitablet Graphics Analysis System with a resolution of 0.00254 cm and an accuracy of 0.0127 cm. Coordinates are transmitted to a PRIME 9955 computer for area calculation and data manipulation with a software program developed at the Virginia Institute of Marine Science. The area of each bed is reported as a mean of three trials. The range of these three trials is not to deviate from the mean by more than 5%.

The perimeter of each SAV bed is defined by a polygon with a linear point density of 50 per chart centimeter (5 m ground resolution). The total number of points defining any SAV bed is dependent on overall bed size. The SAV bed perimeter is stored as X and Y coordinates in centimeters from the quadrangle origin. Perimeters are later converted to latitude and longitude.

A standard operating procedure was developed to aid orderly and efficient processing of data, and to comply with the need for consistency, quality assurance, and quality control. These standard operating procedures include a detailed procedure outlining 46 steps for digitization of SAV maps; a 47-step checklist for editing SAV perimeter computer files; a digitizer log in which all operations are recorded and dated, and which is used to guide and record editing operations; and a flowchart used to track progress of all computer operations, including all changes in file names.

Vegetation Trends in Chesapeake Bay

The distribution of SAV in the Chesapeake Bay and tributaries has been organized into 3 zones and 21 sections (Fig. 3). In 1978, the first baywide survey of seagrasses delineated 16,894 ha with 17.8, 44.0, and 38.2% in the upper, middle, and lower bay zones, respectively (Fig. 4). By 1987, there were 20,230 ha, a 21% increase from 1978, with 14.6, 45.9, and 39.2% in the upper, middle, and lower bay zones, respectively. From 1978 to 1987, there were relatively small changes in most sections of the lower bay zone, and both increases and decreases in sections of the middle and upper bay zones (Fig. 5). The increases were primarily in the upper Potomac River (section 11) and the middle reaches of the bay along the eastern shore (sections 12 and 13). Decreases were in the upper reaches of the bay (sections 3, 4, 5, 6, and 7). Data are not available for seagrass abundance in the bay before 1978, making it difficult to estimate the amount of SAV that had been lost in the Chesapeake Bay up to that time. Qualitative assessments indicated that there may have been in excess of 50,000 ha, at peak levels (Bayly et al. 1978). Thus, current SAV populations may be less than half of those that existed 20 years ago. Several areas exemplify the changes described previously and are discussed in more detail to provide an additional perspective on the changes that have occurred in the bay.

The lower eastern shore (section 14) has had abundant seagrass since 1978 (Fig. 6). *Zostera marina* and *Ruppia maritima* are the dominant species in this area. Because this area is close to the mouth of the Chesapeake Bay, the generally less turbid water apparently allows for a much greater depth penetration of light and thus a greater depth distribution of SAV as compared with western shore areas (Orth and Moore 1988a).

Seagrass in the Rappahannock River (section 16), which consists of *Zostera marina* and *Ruppia maritima,* was abundant along both shores in 1971. There was a rapid decline in seagrass between 1971 and 1974, with continued absence of SAV through 1986. However, since 1987 there has been a rapid increase of *R. maritima* in some downriver areas (Fig. 7). This change has paralleled similar increases observed with this species in other mid-bay areas.

Submerged vegetation in the upper Potomac River was absent in 1978. However, a rapid increase was observed in 1984, with continuing expansion through 1987 (Fig. 8). The abundance in 1987 was the most recorded since the early 1900's and was largely due to the rapid spread of *Hydrilla verticillata,* after its accidental introduction in 1981. Although *H. verticillata* is by far the most dominant species in this region, 12 other species have been reported. The reason for their reoccurrence is unknown, but may be associated with the increase in water clarity created by the dense mats of *H. verticillata* in inshore areas. The increase in submerged vegetation in the upper Potomac River may have been accelerated because of the reduction in the discharge of nutrients by the Blue Plains Sewage Treatment Plant in Washington, D.C. Total suspended solids and phosphate loading have declined. Nitrification began in 1983, changing the main nitrogen input from ammonia to nitrate. Although no definite links between nutrient reductions and seagrass regrowth in this region have been made, these changes in discharge could only have had positive effects.

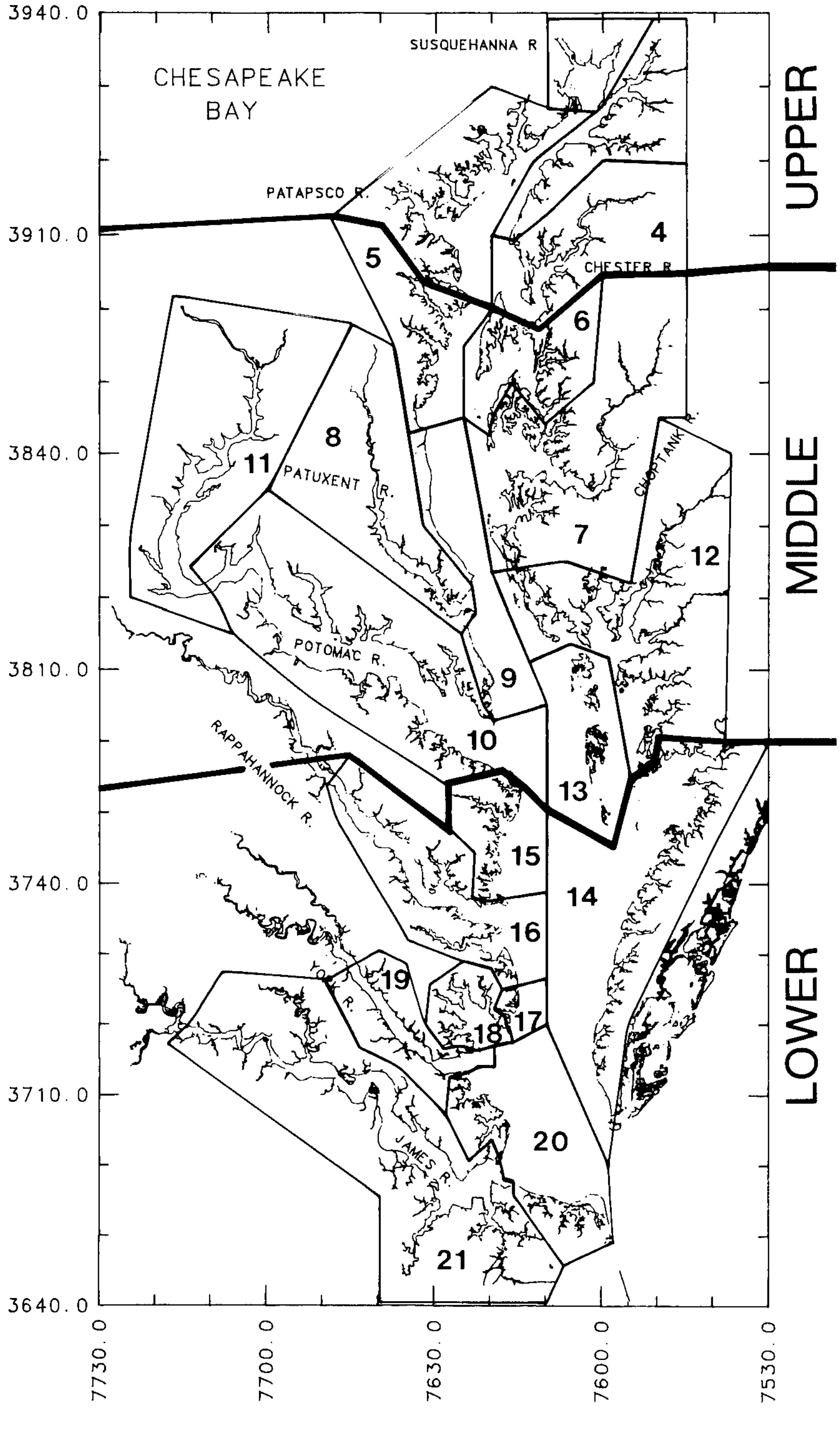

Fig. 3. Chesapeake Bay and tributaries showing delineation of zones (3) and sections (21) developed for discussion of trends of submerged aquatic vegetation.

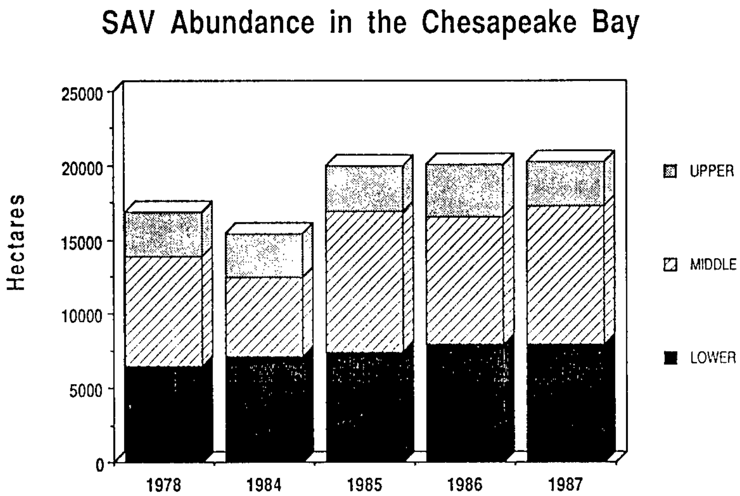

Fig. 4. Abundance of submerged aquatic vegetation by zone for the Chesapeake Bay and tributaries for 1978, and 1984 through 1987.

Summary and Recommendations

Submerged vegetation in the Chesapeake Bay and its tributaries has been an abundant natural resource and, in some sections, it still is. Populations that experienced rapid declines in the 1970's have had some recovery in the 1980's. The recovery in some sections has been substantial and may be due to the improved water quality from reduced upland input of nutrients and sediments. However, large areas of the bay still have the potential to support seagrass populations. Thus, nutrient reduction strategies, including point and nonpoint sources and groundwater inputs as well as reduction in sediment inputs, must be expanded if seagrasses are to remain a part of the Chesapeake Bay's important living resources (Orth and Moore 1988b).

Because of the importance of seagrasses to coastal estuaries and lagoons of the United States, and because of their vulnerability to changes in water quality, we recommend that a major initiative be undertaken to census this resource on a nationwide basis, as is ongoing in the Chesapeake Bay. For most areas we recommend that a combination of low-level aerial photography, flown under strict guidelines, and ground-truth studies, including permanent transects, be established to

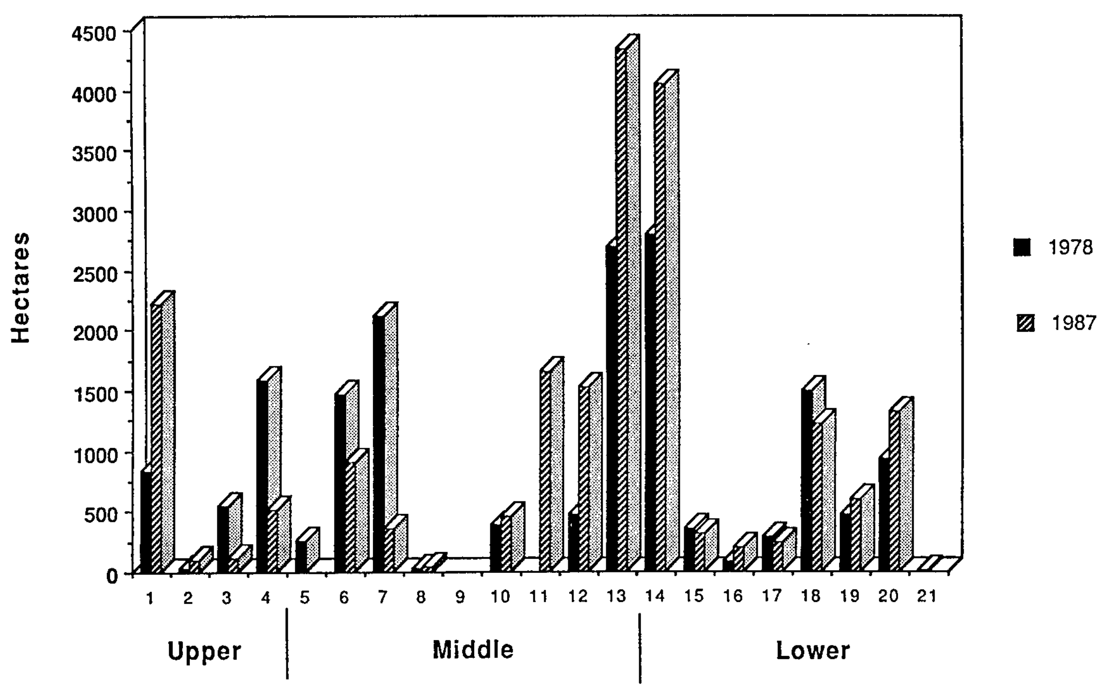

Fig. 5. Abundance of submerged aquatic vegetation for the 21 bay and tributary sections for 1978 and 1987.

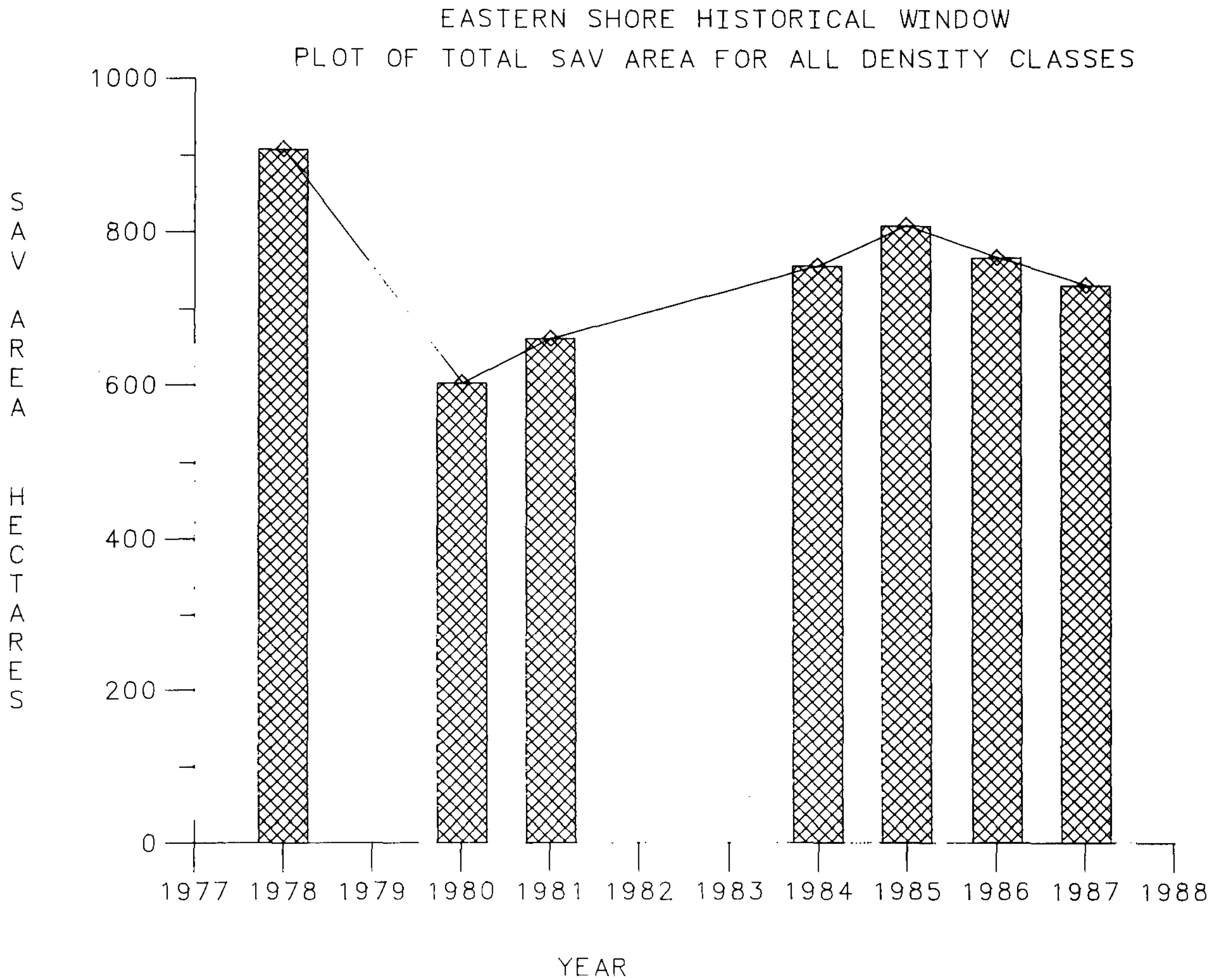

Fig. 6. Abundance of submerged aquatic vegetation (SAV) for a portion of the lower eastern shore of Virginia (section 14), 1978–87.

examine long-term changes in species density and composition. Some regions (e.g., Florida), because of the extent of the seagrass beds, may require high-altitude or satellite photography. However, these baseline data are critical for the proper management of this resource, regionally as well as nationally. A coordinated, cooperative program between Federal and State agencies, in which standardized methods are used, will not only allow an assessment of the changes in distribution and abundance at these different levels, but also will protect existing resources.

Acknowledgments

The monitoring program for SAV in the Chesapeake Bay would not have been possible without the cooperation and financial support of many State and Federal organizations over the past 10 years. These organizations include the U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration's Coastal Zone Management Program, Maryland Department of Natural Resources, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, the Committee to Preserve Assateague Island, and Allied-Signal, Inc. We especially thank R. Batiuk of the U.S. Environmental Protection Agency's Chesapeake Bay Liaison Office, for his continuing encouragement, and A. Frisch, who has made significant contributions to ensure the quality of the data management. H. Neckles provided valuable comments on the initial draft.

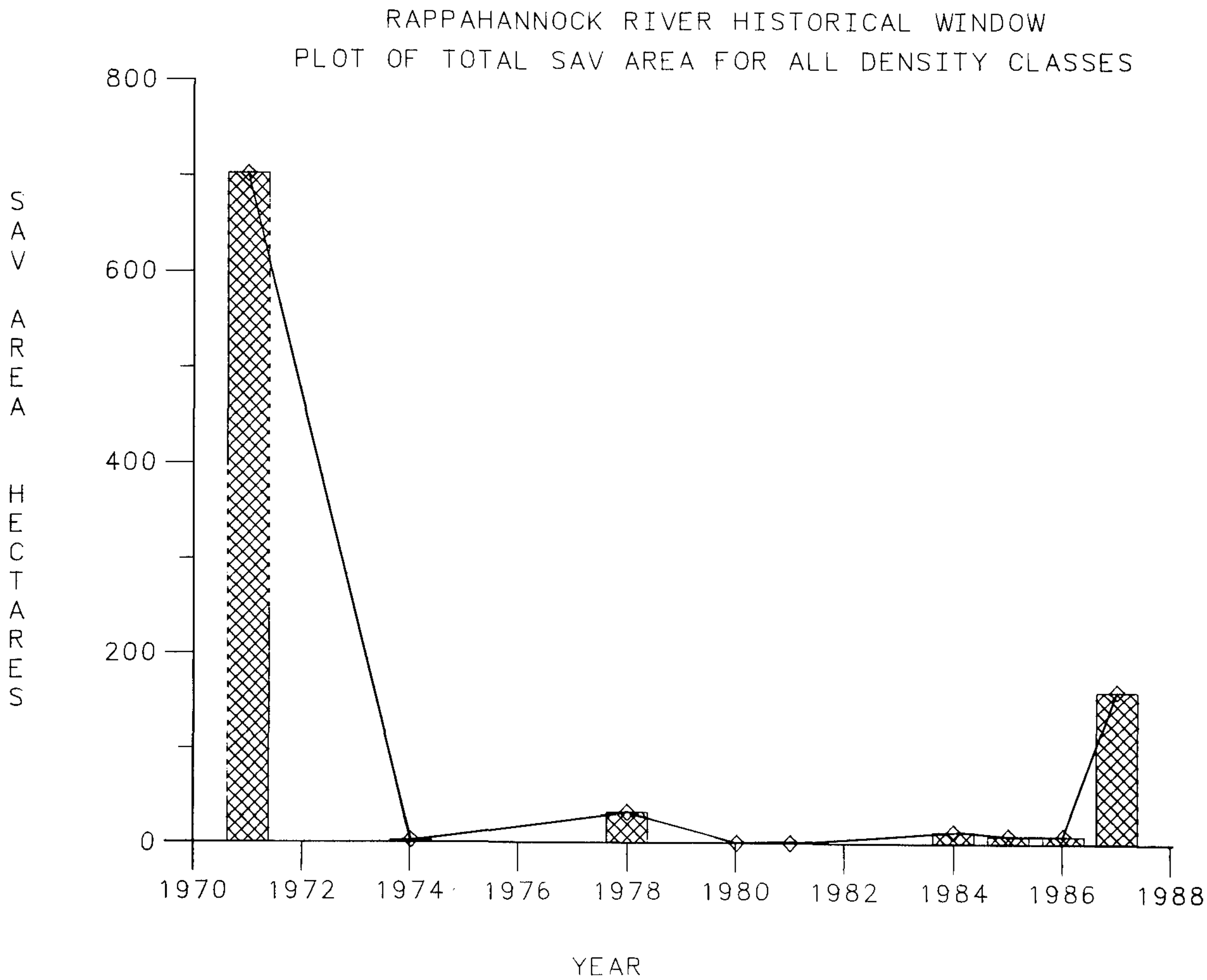

Fig. 7. Abundance of submerged aquatic vegetation (SAV) for the lower Rappahannock River (section 6), 1971–87.

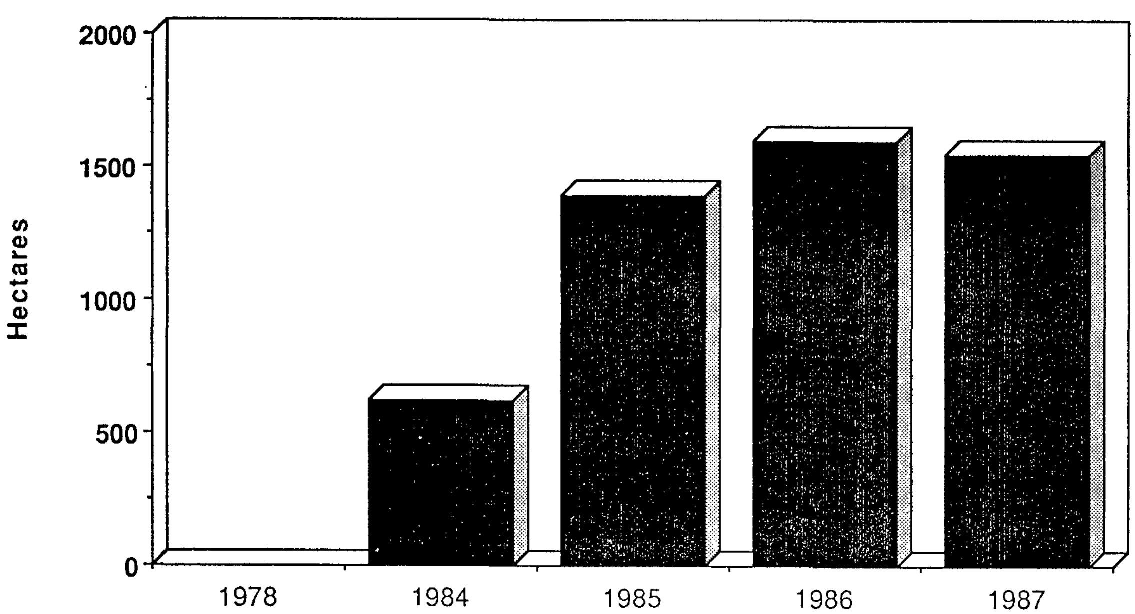

Fig. 8. Abundance of submerged aquatic vegetation for the upper Potomac River area (section 11), 1978–87.

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