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Submerged Aquatic Vegetation in the Chesapeake Bay: A Barometer of Bay Health

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INTRODUCTION

In 1978, a program was initiated in the Chesapeake Bay region to investigate the decline of submerged aquatic vegetation (SAV), potential factors that may have led to its decline, its distribution and abundance, and its role and value. The program began with little available background data, but some very basic questions about SAV in the Bay were answered in the approximately three years of research that were funded. For example, it was determined that the decline of SAV was Bay-wide. All SAV species were affected and the decline was unprecedented in the recent history of the Bay. A second important finding was that the decline of SAV was most probably not related to any specific contaminant per se (e.g., herbicide contamination) but appeared to be related to deteriorating water quality in the Bay. Research has demonstrated that SAV species are very sensitive to environmental perturbations, especially those that affect the quantity of light reaching the plant surface.

Managers and citizens have become increasingly aware of the importance of SAV in ensuing years, and citizens have become actively involved in several programs such as the SAV Hunt program, which has provided ground-truth information to the Bay-wide aerial monitoring program. Both Maryland and Virginia have also initiated efforts to restore SAV in currently denuded areas and to develop an understanding of the relationships between SAV survival and environmental quality. These and other projects have yielded significant results that have assisted in Bay management. More research certainly needs to be done. More important, scientists and managers must work together to develop sound strategies for SAV, in concert with an overall Chesapeake Bay policy.

Our attempt in the SAV session at the Baltimore Chesapeake Bay Research Conference was to bring the scientist, manager, and citizen together to discuss recent management needs and research results in four major areas: distribution and abundance, water quality, natural resource value, and restoration. We hope the results of this blend will yield a new perspective on Bay SAV and identify what we must do to manage this resource effectively.

DISTRIBUTION AND ABUNDANCE: A DECADE OF CHANGE

An important component of the early program was an integrated aerial mapping survey of Bay-wide SAV distribution in 1978. This first synoptic aerial view of the Bay has served as a baseline for more recent work.

In attempting to examine historical trends of SAV distribution, it became clear how important comprehensive distributional data are in relating the SAV resource to water quality, climatic factors, or biological changes. Although regular monitoring of SAV distribution was strongly recommended on the basis of the 1978 study, it was 1984 before the next Bay-wide survey was conducted. (SAV was mapped in Virginia in 1980 and 1981; in Maryland in 1979. Maryland has conducted an annual ground survey of SAV since 1972, and the U. S. Geological Survey [USGS] has been monitoring SAV in the Potomac River since 1978.) Subsequent Bay-wide surveys were made in 1985, 1986, and 1987. Studies were also conducted in the Potomac River in 1981 coinciding with the introduction of *Hydrilla verticillata* to the Dyke Marsh area in the tidal freshwater reach of the river. Local citizens have assisted in ground-truthing much of the aerial photography.

The focus of this section of the session was to

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address questions regarding the recent changes in SAV distribution:

- What has happened with SAV in the last decade?
- Has the current SAV distribution information been useful for the manager and scientist?
- What is the best monitoring strategy given the current levels of financial commitment from the federal and state agencies?
- What is the future of *H. verticillata* in the Potomac?

The Bay-wide Status of SAV

The 1978 aerial survey revealed a total of approximately 17,000 hectares of SAV (Figure 1), of which 56% was found in the lower Bay zone (an area from Smith Island to the mouth of the Bay), 27% in the middle Bay zone (Smith Island to the Chesapeake Bay Bridge), and 17% in the upper Bay zone (Bay Bridge to the Susquehanna River). Major areas of SAV abundance documented in this first survey were: Tangier-Smith Island area, Mobjack Bay in Virginia, lower Eastern Shore from Cape Charles to Pocomoke Sound, Eastern Bay area, Choptank River, and Chester River. By 1986, approximately 19,000 hectares of SAV were present in the Bay with 64%, 21%, and 14% found in the lower, middle and upper Bay zones, respectively. Major areas of SAV abundance included not only the same areas as in 1978, but also the tidal freshwater area of the Potomac River and the middle Eastern Shore area, especially around the Barren Island and Honga River in Maryland. Additional increases have been observed in many other sections of the Bay, especially near existing beds of SAV. Spread of SAV has occurred from seed dispersal, which may be one important mechanism not only for bed maintenance but also for revegetation of denuded areas. Reasons for the recent increase of SAV in the mid-sections of the Bay are presently not known. Caution is urged, however, in attempting to relate this modest increase to the recent Bay cleanup efforts. Climatic factors, such as reduced rainfall in the Bay region in recent years, may be one of several important but unknown controlling factors.

The Bay-wide monitoring of SAV has provided valuable information for resource managers including the most up-to-date data on the distribution and abundance of SAV. Products of the annual SAV surveys include (1) photographic imagery, which in addition to documenting SAV occurrence is useful for other activities (land use studies, shoreline erosion studies, etc.); (2) maps based on USGS topographic quadrangles (scale of 1:24,000) delineating all beds of SAV including species information as available from field surveys and ground-truthing; and (3) digitized bed outlines and other accompanying data, which are now stored on computer and can easily be networked into regional or Bay-wide information systems.

For the scientists, the annual survey has provided a synoptic view of the distribution of SAV for the entire Bay in one year. These data serve as an important baseline that will allow the accurate assessment of SAV changes from region to region. Because SAV systems respond to some water quality changes, SAV may be a good indicator to assess the progress of the Bay cleanup. Defining relationships between the water quality conditions and SAV abundance will be very important to Bay managers and regulators who have the ultimate responsibility of insuring the long-term viability of the Bay and its living resources.

The relevance of the monitoring data to the Bay management efforts suggests strongly that this monitoring program should be continued. Scientists are currently conducting the aerial survey annually. This activity represents a modest commitment of funds, which to date have been provided through a cooperative effort of state and federal agencies. Acquisition of adequate funds for an integrated annual survey has been difficult, and when funding is incomplete, significant modifications to the products must be made. Since significant changes can occur rapidly and the natural variability in the system is only beginning to be quantified, ideally the survey should be continued annually, with both aerial photography and digitized computer mapping. A second option would be acquisition of the aerial photographs each year with mapping of all beds and ground-truthing conducted only every second year. SAV abundance might be determined in alternate years by subsampling. If significant changes occurred during the two-year interval, reference could be made to the aerial photographs from the intervening year to determine the timing of the changes. Such an approach may, however, threaten the continuity of the program with repeated mobilization and demobilization of personnel and equipment.

If SAV is to be used as an indicator or "barometer" of Bay health, a commitment must be made at both the state and federal levels to insure that this program continues and is adequately funded. A valuable data base has been developed that has been useful in the development of the Bay cleanup efforts. Every effort should be made to continue the program.

Potomac River: Boom or Bust

The Potomac River provides a case example of a system that has undergone large changes in SAV in the last decade. This region has been known for periods of either abundant SAV, mostly with exotic species, or no SAV at all. Abundant native SAV species were noted in the early 1900's. *Trapa natans*, an exotic, reached

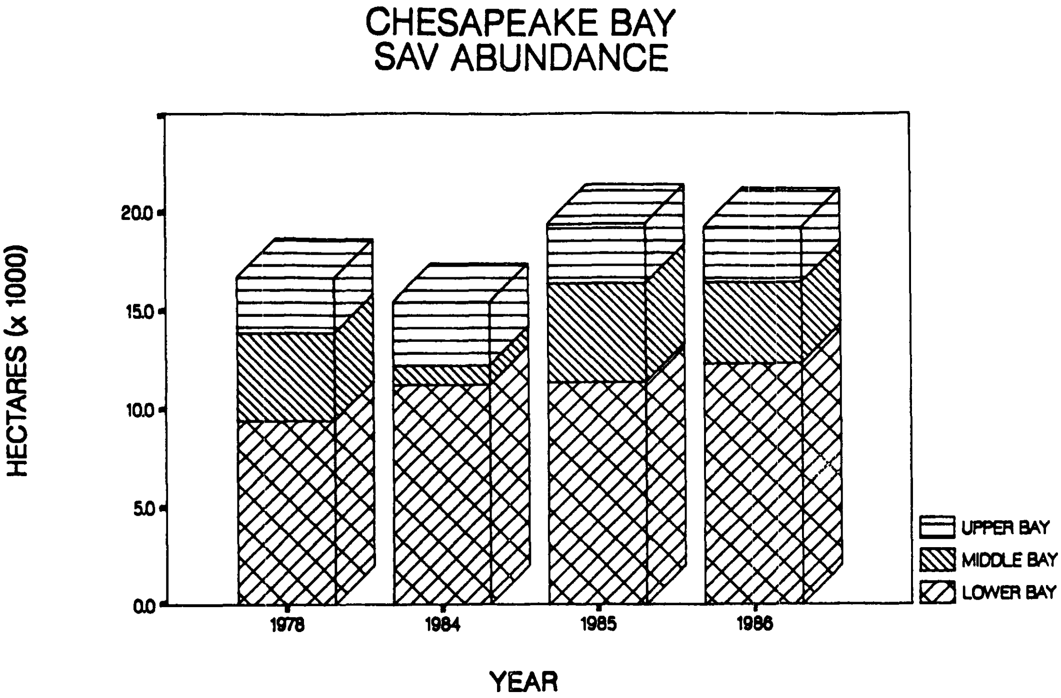

Figure. 1. Abundance of SAV in the three major zones of the Chesapeake Bay for 1978, 1984, 1985, and 1986.

nuisance levels in the tidal portion of the Potomac in the 1920's–1930's and 1950's, and *Myriophyllum spicatum* (another exotic) was very abundant in the transition zone in the late 1950's and early 1960's. Native vegetation in the tidal freshwater and transition zone has been almost absent since the 1920's. *Zostera marina*, a native species that was present in the higher-salinity sections of the river, has been absent since the 1960's. A 1978-1981 survey of the tidal Potomac River and estuary found that SAV was virtually absent from the tidal river and was maintaining only low population levels in the transition zone of the estuary.

Twelve species of SAV were found in the tidal sections of the Potomac in 1983, including *Hydrilla verticillata*, an exotic from southeastern Asia. In 1983 and 1984, there was patchy distribution of all SAV species with *H. verticillata* concentrated mostly on the Virginia side, near Dyke Marsh where it had mistakenly been planted. Between 1984 and 1987, SAV increased from 243 to 1580 hectares and spread downriver. *Hydrilla* has increased from a small percentage of the species in a diverse population of plants, to near domination of the upper tidal river. It became firmly established in Mallows Bay at the upper end of the transition zone. *Hydrilla* could eventually cover all shallow (<2.5 m at mean low water) areas in this section of the Potomac. It also has the potential to become established in similar zones in all the tidal rivers feeding the Chesapeake Bay, although its ultimate distribution will likely be limited by the salinity of the water (approximately 5 o/oo).

The Role of the Citizen

The Bay-wide SAV survey using aerial photography requires considerable ground-truthing to substantiate the presence and species composition of SAV on the photographs. Because ground-truthing of all the SAV beds by trained scientists is impossible, a plan was devised to organize Bay citizens to assist in an "SAV Hunt". This was a cooperative venture between the respective staffs of the U. S. Fish and Wildlife Service, the Chesapeake Bay Foundation, the Alliance for the Chesapeake Bay (formerly the Citizens Program for the Chesapeake Bay), the Maryland Department of Natural Resources, and the Virginia Institute of Marine Science. In addition, members of the Maryland Charterboat Association, funded by Maryland's DNR, also participated in the ground-truthing program. Using citizens to help in the ground-truthing serves three purposes: it provides additional information for the annual aerial survey; it is valuable in educating the citizen about the importance of SAV; and it provides concerned citizens with an opportunity to actually get involved and be a part of the whole "Save the Bay" effort.

Citizens and charterboat captains were asked to go to beds delineated on maps and determine the bed's presence or absence for the current year. Any new beds found were also to be reported. Species information was collected if species identification could be reliably determined. For the last three years, approximately 150 citizens and 15 charterboat captains have participated annually. Results from the 1986 survey showed that 673 SAV beds were field-checked in Maryland and Virginia. These data have provided valuable information as to the presence of SAV in many areas of the Bay not previously examined. The experience gained from this program has been invaluable for both citizens and scientists, and the program certainly should be continued.

WATER QUALITY: HOW CLEAN MUST THE BAY BE FOR SAV?

There is widespread agreement among scientists, citizens, and managers that improving water quality in the Bay is the number one issue today. As with other aquatic living resources, poor water quality is a major factor affecting SAV growth and production. If it is to remain a viable natural resource, attempts to set nutrient and chlorophyll standards for the Bay must therefore take into consideration the nutrient and light requirements of SAV. This will be no simple task. There are many different SAV species in the Bay with different life history patterns and potentially different growth requirements. SAV grow in rivers whose watershed characteristics are different and where strategies for nutrient control may require different sets of rules.

Important questions that should be addressed related to the SAV living resource are:

- What parameters shall be used in setting goals for water quality criteria or standards?
- Is SAV being considered an important component in the development of the overall water quality criteria?
- Should water quality criteria for SAV be developed for the entire Bay or should there be basin-by-basin criteria?
- What data are needed for setting criteria and how are they being obtained?
- How realistic are these criteria?

Development of Water Quality Criteria: How Critical Is It For The Bay Cleanup?

Since 1983, most of the research and planning efforts for restoring and protecting the Chesapeake Bay have focused on documenting the present water quality of the bay and refining strategies for reducing or stabilizing nutrient and contaminant loads. Strategies based only upon traditional water quality standards, however, cannot necessarily ensure the restoration and protection of living resources.

There is a growing recognition that the Chesapeake Bay must be managed from an ecosystem perspective, requiring innovative approaches to resource and habitat management. The 1987 Chesapeake Bay Agreement states the Program's primary goal is to "provide for the restoration and protection of the living resources, their habitats, and ecological relationships."

Recognition of restoration of living resources as the ultimate goal of the Bay Program has caused a reexamination of how to effectively focus regulatory and management actions to protect or improve habitat quality. Since the early 1970's water quality management has focused on meeting the fishable/swimmable/drinkable goals of the Clean Water Act through the application and enforcement of water quality standards. EPA criteria and state standards are still limited to conventional water pollution parameters (e.g., dissolved oxygen, temperature), and to some toxic metals and organic compounds listed as EPA priority pollutants. The underlying assumptions have been that reducing pollutant loads to meet water quality standards would result in meeting the designated use classifications for certain stream segments. Existing water quality criteria and standards do not well serve the needs of some living aquatic resources and should be reviewed in light of the Bay's overall restoration.

One of the critical limitations of existing state standards is in geographical application. In Maryland and Virginia, use designations within the tidal Chesapeake Bay are geographically defined by the boundary where tidal fresh waters meet oligohaline waters in the tributaries with the mainstem portion of the tributaries. Jurisdictional boundaries between the states at the mouth of the Potomac constitute another artificial barrier to the Bay-wide application of water quality standards.

The Living Resources Task Force, in its September 1987 report on Living Resources Habitat Requirements, suggested that Chesapeake Bay living resources be managed on a regional basis. Regional habitat objectives, based on protecting the combined most sensitive life stages of the representative resources living within that habitat, should be applied on the basis of geographical distribution of living resource habitats. Ideally, only habitat, not political boundaries, would be the determining factor for their application.

Submerged aquatic vegetation has come to play a significant role in the development of regional habitat objectives. For example, it provides the means to bridge the gap between the stated management goal to reduce total nitrogen and phosphorus inputs to the bay by 40% and specific numerical targets for Bay nutrient levels and overall habitat quality. Since eutrophication has been related to SAV decline, SAV can be an important indicator of regional water quality. Lacking in all existing EPA criteria documents and state standards so far are the nutrients, as well as specific indicators of light transparency, both of which are fundamental to the management of the Bay as an ecosystem. As its restoration to historical abundance has been a key objective of the Chesapeake Bay Program, SAV's utility as an indicator organism is thereby strengthened.

Turbidity, total suspended solids, secchi depth, light intensity, light attenuation, chlorophyll α, dissolved inorganic nitrogen, dissolved inorganic phosphorus, herbicides, sediment type, salinity, pH, temperature, as well as the physical environment (e.g., fetch, waves, etc.) are the types of SAV habitat requirements which could be used in drafting of regional habitat objectives. Laboratory experimentation with field validation would then be necessary to confirm SAV habitat requirements for the above listed parameters. Experimentation should focus on different salinity regimes, representing different species groups' habitats.

Implementation of regional SAV habitat objectives could be the management tool to bridge the existing gap between use and application of existing water quality criteria and standards. In the years to come, linkage of water quality and habitat conditions to changes in living resources would become confirmed through scientific study and monitoring.

Water Quality Criteria

The desire to establish water quality standards based on living resource requirements has focused attention of managers and scientists alike on the necessity for relating potentially important environmental factors to SAV growth and survival. Although research has suggested that various environmental factors can influence production and consequently survival, the actual levels necessary to support growth and survival have only recently been investigated. In the late 1970's researchers at the University of Maryland studied the relationships between SAV survival and eutrophication using 1/8-acre ponds vegetated with native macrophyte species and enriched with fertilizer. Results suggested a direct relationship between nutrient loadings and SAV survival. At the Virginia Institute of Marine Science, investigations with more marine SAV species suggested that SAV in this region may be living close to their levels of environmental tolerance and that, within the physiological constraints of temperature and salinity for the area, reductions in light may be the principal factor controlling SAV growth and survival.

In 1984 a research group at the Virginia Institute of Marine Science began to investigate the relationships between environmental quality and SAV growth and survival in a series of field studies. Objectives were threefold: first, to monitor the environmental quality along an upriver gradient of sites that both currently and formerly supported vegetation; second, to determine the potential for plant production and survival at these sites; and third, on the basis of these two sets of information to determine the levels of environmental variables that characterize the SAV communities in the region. Biweekly sampling of a series of sites in shoal areas along the York River was undertaken. Upriver stations were characterized by complete decline of SAV, while in downriver stations the loss of vegetation decreased with distance to the mainstem of the bay. In addition to the environmental monitoring, eelgrass, the dominant species of macrophyte in the region, was transplanted each fall to determine the potential for SAV growth, production, and survival at the sites.

In 1985 researchers at the University of Maryland, Horn Point Environmental Laboratory, initiated a similar monitoring program in the Choptank River along the upper Bay's Eastern Shore. As in the York River, SAV survived only along the lower section of the river. At nine sites along the tributary, plugs of native species including widgeon grass, redhead grass and sago pondweed were transplanted. The transplants were successful only in the most downriver sites. Since SAV species in this region exibit shoot growth for approximately a six-month period, monthly measures of water quality obtained along a gradient of sites in the Choptank were averaged over this time period to compare stations in the upriver and downriver areas.

Results of both of these studies suggest that there may be similar thresholds for SAV growth in widely divergent areas of the bay. They also suggest that differences between sites that support or do not support growth are quite small and that very small changes in environmental quality can have a significant affect on the vegetation. While these studies are an important step in defining water quality standards many questions remain unanswered. How, for example, do these water quality models fit other river systems in the Bay? What are the interractive relationships between the various factors? What are the seasonal aspects of susceptibility to limiting factors? What role might sediments play in regulating SAV? Other topics important to managers include the impacts of marinas and boating activity on SAV beds. These and other questions need to be investigated, allowing Bay managers to develop effective strategies for restoring living resources in the Bay system.

NATURAL RESOURCE VALUE: A DIFFERENT LOOK

One of the most often-repeated comments made in the last decade about SAV has been that these areas are an important habitat, particularly as a nursery and feeding ground for many species of invertebrates and vertebrates. SAV beds support much greater densities of macroinvertebrates than adjacent unvegetated areas. Rates of secondary production are extremely high in SAV. The beneficial aspects of SAV have been recently illustrated in the Potomac River. Water clarity has increased substantially in the vicinity of the SAV beds. Positive relationship has been observed between the spread of *Hydrilla* and increased waterfowl utilization as well as increased catch of finfish near these beds.

As pressures continue to grow due to development of the shoreline and watershed of the Bay region, a number of important questions remain:

- Do managers need to know more about SAV functioning to conserve SAV?
- Are all SAV beds considered of equal importance?
- What are the relationships between the role and value of SAV and the size of a SAV bed, the abundance of SAV in an area, or the location of the bed in the estuary?
- Do SAV beds enhance local or Bay-wide productivity?
- Are all SAV beds the same in terms of resource value for individually important species such as the blue crab?

Resource Value—What More Do We Need to Know?

A considerable body of published material describes the resource values of SAV and justifies its conservation. Additional information on biological values is needed, however, particularly concerning which fauna are most dependent on SAV and which SAV species form the most important useful habitat. For example, what are the relationships between SAV in the Bay and waterfowl usage?

One poorly understood relationship is that of SAV bed size and bed function. Are the values of sparsely vegetated beds the same as for a large, densely vegetated area? Are they heavily used by fish and invertebrates, and are they important in habitat expansion? What is the role and value of areas that previously supported SAV but are now unvegetated? Should they be replanted as part of an overall management plan?

SAV beds are utilized by diverse groups of animals. Although their abundances are usually much greater in SAV than in adjacent unvegetated areas, few are exclusively found associated with SAV. For example, some waterfowl species such as canvasbacks and Canada geese, which relied heavily on SAV in the past for food, were able to shift their diets to other sources (e.g., field corn or clams), when SAV declined. Other species, such as redhead ducks, have not shown this flexibility, and their numbers are much reduced in the Bay.

Our understanding of how the large secondary production component fuels other systems, especially species (such as most finfish) that are migratory and not directly dependent on SAV, is very poor. We do not know what proportion of this production remains within the bed and how much may be exported. Because in the past SAV beds occupied a much greater proportion of the Bay bottom, their relative influence compared to today must have been much greater.

The high abundances of fauna in SAV beds have often been related to the refuge from predation they offer. High abundances may also result from enhanced settlement into these habitats. SAV baffles currents and wave action, resulting in deposition of fine sedimentary material; and larvae of invertebrates may act like sediment particles and be selectively deposited in the SAV beds. We have very little information on larval behavior with respect to habitat selection and the settlement process. The high abundances of animals in SAV may first be set by larval supply rates and processes acting on supply rates into a grassbed. Once in a grassbed, larval behavior, vegetation type and density, current speeds, and volume flux all contribute to settlement abundances. Once larvae are established, post-settlement factors affecting survivorship such as predation become very important.

The importance of SAV in blue crab populations of the Chesapeake Bay has been a topic of debate since the large decline of SAV in the 1970's. Blue crab populations have not declined as dramatically as SAV. Blue crab populations are not completely dependent on SAV; states such as Georgia and South Carolina have large blue crab stocks but do not have seagrasses. The Bay region, however, has by far the highest catch of blue crab throughout its entire range, perhaps due to the presence of SAV for several critical life stages.

Juvenile blue crabs are significantly more abundant in SAV beds than in adjacent marsh creeks or bare sand areas. Blue crabs recruit into the Bay as planktonic megalopae (the last stage before the crab assumes primarily a benthic mode), and studies suggest settlement may be much higher in the lower Bay than other sections. Since SAV beds in the lower Bay have declined the least and the lower Bay contains over one-half of all SAV in the Bay, the impacts of SAV loss on the blue crab may not be as large as once thought. Marsh creeks, although of lesser value, may be important nursery sites in areas without SAV. Studies of the relative role of vegetated areas (marshes vs. seagrasses) and the proximity of these areas to larval supply will yield important information on the value on these areas to commercial stocks, not only for the blue crab but also for many other species.

RESTORATION

The loss of SAV in many sections of the Bay prompted scientists and managers to ask whether SAV beds could ever recover naturally, given that whole rivers were completely denuded and were distant from sources of naturally occurring stock. This concern led both Maryland and Virginia to develop restoration programs. Questions central to restoration programs are:

- Was the lack of revegetation due to chronic poor site habitat, poor water quality, or simply a lack of propagules?
- What are the best species to use?
- Are single-species or mixed-species plantings superior?
- What is the best spacing of plants to insure the most rapid recovery of an area?
- How important are patch size and location in improving transplanting success?

Restoration with SAV, although similar to marsh planting, presents a unique problem to the manager and researcher in that all work must be done underwater. Choosing sites for replanting is critical, and success may indeed be related to getting as rapid a spread as possible. In 10 years of pilot transplanting, there have been both successes and failures. During this period we also observed rapid natural recovery of SAV in several areas that provided crucial insights regarding SAV colonization of new areas. These studies suggest that there may be a distinct successional component in these events. Restoration is an important management objective today because of population pressure with its potential for disturbance of SAV habitats. As scientists and managers we must ask what the future of SAV is in the 21st century, given the tremendous projected population growth in the Bay watershed.

Population Growth and SAV—What Can Be Done?

The population in the 64,000-square-mile Chesapeake Bay Basin was estimated to be 13 million in 1980 and is predicted to grow to 16 million people by the year 2,000. Although the current growth rate (1% annually) is anticipated to slow as we enter the 21st century, Bay managers will still be confronted with increasing pressures on dwindling natural resources such as SAV.

SAV is provided indirect protection by point and non-point water pollution control programs, which include sediment and erosion control programs, agricultural best management practices, shore erosion control, and sewerage treatment programs. We need to encourage the expansion and upgrading of these activities and assure that regulatory policies include the conservation of SAV resources. Since regulatory programs provide SAV with direct protection from specific development activities, SAV management has developed into a multiagency responsibility that must be as well coordinated as possible. Regulatory agencies include the U. S. Army Corps of Engineers, the Maryland Department of the Environment, the Maryland Department of Natural Resources, the Virginia State Water Control Board, and the Virginia Marine Resources Commission. In addition, the U.S. Fish and Wildlife Service, Environmental Protection Agency, National Marine Fisheries Service, Virginia Institute of Marine Science, as well as other organizations, provide environmental review on development activities.

In order for these regulatory agencies to adequately protect SAV, they need guidance on methods to minimize the impacts of development activities. Recommendations for minimizing these impacts could include the following:

- No dredging should be permitted between April 15 and October 15 on project sites that currently support or have historically supported SAV;
- Due to differing abundances of SAV between watersheds, one site visit during the growing season (April 15–October 15) should be required on proposed project sites that currently support or have historically supported SAV;
- Watershed-by-watershed protection plans should be developed for the protection of SAV.

In cases where development impacts cannot be avoided, compensation should be given careful consideration. Any type of compensation policy might be based on the premise of no net loss of SAV Bay-wide due to development and associated projects. Strict guidelines should be established for compensation projects, and compensation should be viewed as the last alternative after avoidance and minimization. Compensation/mitigation projects should attempt to be acre for acre, species for species, and habitat value for habitat value. It may also be useful to expand mitigation projects to include those which increase species diversity in already existing beds. For small project impacts, the use of compensation fees should be given consideration. These compensation fees could be used for larger transplant, research, or monitoring projects. Whatever the final management plan, achieving a good consensus will require considerable interaction between the various regulatory and advisory groups.

The use of compensation for ameliorating the adverse impacts of development is based on the premise that transplanting is a viable technology. However, transplanting efforts have met with limited success nationwide and the cost for these projects has been extremely high. Currently, scientists view transplanting as most useful in small-scale projects designed to increase the knowledge of SAV life cycles, transplanting techniques, and water quality parameters and sediment characteristics necessary for healthy SAV growth. Ultimately, small-scale transplanting projects could be used as a gauge for measuring the local effectiveness of Bay clean-up efforts.

Transplanting Programs in the Chesapeake Bay — Progress

The two main goals of SAV restoration programs initiated by Virginia and Maryland over the past few years have been to understand those factors controlling SAV distribution and abundance, and to develop improved methodologies for transplanting in this estuary.

Transplanting SAV can be a difficult undertaking. SAV planting is similar to marsh planting in that (1) whole plants are used in many cases; (2) seasonal timing is important; (3) substrate elevation, sediment type, and salinity are important environmental factors; (4) growth and survival are improved with fertilizer applications to sediments; and (5) plantings are subject to disturbances from physical and biological factors. Major planting differences also exist: (1) SAV are more difficult to harvest, store, transplant, or plant; (2) SAV are subject to additional stress of water quality conditions; and (3) SAV transplants are more difficult to monitor for success and failure.

Transplanting efforts in the Bay have been focused primarily on areas that formerly supported SAV but currently have little or no vegetation. At the Virginia Institute of Marine Science, transplanting has been conducted principally with the seagrass, *Zostera marina*, in the western tributaries of the lower Bay (York, Piankatank, Rappahannock, and Potomac Rivers). At the University of Maryland, Horn Point Environmental Laboratory, transplanting has been undertaken with *Ruppia maritima* and other low-salinity species in the Choptank River. In the Susquehanna Flats and Sassafras River regions, investigators at Harford Community College have utilized *Vallisneria americana* and other freshwater species in their transplanting attempts. Finally, scientists at the USGS have focused their efforts in the upper Potomac River on *V. americana.*

Most transplanting has been done with whole plants, both with and without sediment, because of the availability and ease of collection. The use of tubers and seeds is currently being investigated.

Plantings have varied from small test plots of 1–25 m^2, to larger plots of 900–7200 m^2. Various plant densities and patch sizes within the plots have been tested for their effect on survival. Transplants have been most successful in areas that currently support low abundances of SAV, although regrowth has been generally slow. Regions distant from existing SAV have usually had the poorest success. In some well-monitored experiments differences in success can be associated with differences in water quality. In a number of sites success can be directly related to site exposure. Timing of planting is critical. For example, *Z. marina* planted in the fall is more successful than at other times of the year; *V. americana,* in contrast, does better when planted in the spring. Native stock (for both plants and tubers) have generally yielded greater success than non-native stock.

CONCLUSIONS

Since interest was first focused on SAV in the late 1970's, SAV has come to be recognized not only as a habitat important in its own right, but also to some degree as a model for the entire Bay environment. Requirements for SAV growth, including water that is low in suspended sediments, dissolved nutrients, and phytoplankton, represent what many consider good overall Bay water quality. Because observations worldwide indicate that the health of submerged grass communities can be used as an early indicator of eutrophication, SAV abundance and diversity have been judged to be barometers or indicators of Bay health, and SAV community requirements will be important in the development of regional habitat objectives.

Management of SAV in the Bay may also serve as a model for management of other important Bay resources. It is a management approach that recognizes the importance of setting goals, objectives and plans based on good scientific knowledge, and where the knowledge is lacking, having at hand the mechanism for asking the appropriate questions so that the gaps may be filled. To accomplish this a good relationship has been developed between Bay SAV scientists and Bay managers. This relationship has been fostered by broad public support and to some degree by active participation in SAV programs.

It was the objective of this session of the conference to bring the manager and scientist together to provide not only an update on current research findings, but also a forum for an exchange of understandings. Review of SAV monitoring programs illustrated that refinement is continuing in a program that has had widespread usefulness and is well prepared to participate in the geographic information systems being developed for the Bay region. Yearly monitoring has demonstrated some recent regrowth of SAV in several regions of the Bay and has shown overall levels significantly higher than in 1978, although nowhere near pre-decline levels. Participation by citizens in the monitoring program has been positive and provides important ground-truth information that in most cases is quite reliable. The development of water quality criteria has been continued, with initial threshold levels established for some species in some areas. The goal of these studies is to assist the managers in setting regional water quality standards based on the requirements of living resources rather than only on traditional water quality management criteria. Investigations further defining the role and value of SAV habitats have been undertaken, along with transplanting studies that assist scientists and managers in understanding the factors limiting natural revegetation. These studies have also provided potential mitigation and compensation tools, the usefulness of which must be further identified and discussed. Regulatory offices must be assisted in setting policies that conserve SAV resources and in developing plans that implement these policies. In total, then, this session recognized that the approach to understanding and managing this important resource is multifaceted and that improvements in the quality of the Bay environment can be obtained in part by managers asking the right questions and scientists providing the correct answers.

REFERENCES

Below are listed many of the major contributions made by Bay scientists toward the understanding of SAV in the Bay. This is not meant to serve as an exhaustive list, but rather to indicate appropriate material from the last decade that may be readily accessible in most libraries. Much of the material has been referred to in this paper. The reader is referred to Stevenson and Confer [1978] for an exhaustive listing of material published before 1978.

Boynton, W. R. Ecological role and value of submerged macrophyte communities: a scientific summary. In: Macalaster, E.; Barker, D.; Kasper, M., eds. Chesapeake Bay Program Technical Studies: A Synthesis. U.S. EPA, NTIS, Springfield, Virginia.; 1982: p. 428-502.

Boynton, W. R.; Kemp, W. M.; Hermann, A. J.; Kahn, J. R.; Schueler, T. R.; Bollinger, S.; Lonergan, S. C.; Stevenson, J. C.; Twilley, R.; Staver, K.; Zucchetto, J. J. An analysis of energetic and economic values associated with the decline of submerged macrophytic communities in Chesapeake Bay. In: Mitsch, W. J.; Bosserman, R. W.; Klopatek, J. M., eds. Energy and ecological modelling. Developments in Environmental Modeling. Elsevier Scientific Pub. Co., Amsterdam.; 1981: p. 441-454.

Boynton, W. R.; Hall, C. A.; Falkowski, P. G.; Keefe, C. W.; Kemp, W. M. Phytoplankton productivity in aquatic plants. In: Lange, O. L.; Nobel, P. S.; Osmond, C. B.; Ziegler, H., eds. Physiological Plant Ecology, IV. Springer. Berlin; 1983: p. 305-327.

Brush, G. S.; Davis, F. W.; Stenger, C. A. Biostratigraphy of Chesapeake Bay and its tributaries: a feasibility study. U.S. EPA Final Report, Grant No. R806680, 68 p.; 1981.

Callender, E.; Carter, V.; Hahl, D. C.; Hitt, E., eds. A water-quality study of the tidal Potomac River and estuary - an overview: U. S. Geological Survey Water-Supply Paper 2233:46 p.; 1984.

Carter, V.; Gammon, P. T.; Bartow, N. Submersed aquatic plants of the tidal Potomac River. U. S. Geol. Sur. Bull. 1543, 58 p.; 1983.

Carter, V.; Bartow, N. The effects of grazers and light penetration on the survival of transplants of *Vallisneria americana* Michx in the tidal Potomac River, Maryland. Aq. Bot. 23:197-213; 1985.

Carter, V.; Rybicki, N. B. Resurgence of submersed aquatic macrophytes in the tidal Potomac River, Maryland, Virginia and the District of Columbia. Est. 9:368-375; 1986.

Carter, V.; Rybicki, N. B. Resurgence of submersed aquatic macrophytes in the tidal Potomac River, Maryland, Virginia, and the District of Columbia. Est. 9:368-373; 1987.

Correll, D. L.; Wu, T. L. Atrazine toxicity to submersed vascular plants in simulated estuarine microcosms. Aq. Bot. 14:151-158; 1982.

Cunningham, J. J.; Kemp, W. M.; Lewis, M. R.; Stevenson, J. C. Temporal responses of the macrophyte, *Potamogeton perfoliatus* L., and its associated autotrophic community to atrazine exposure in estuarine microcosms. Est. 7:519-530; 1984.

Davis, F. W. Historical changes in submerged macrophyte communities of upper Chesapeake Bay. Ecol. 66:981-993; 1985.

Delistraty, D.; Hershner, C. Determination of adenine nucleotide levels in *Zostera marina* (eelgrass). J. Appl. Biochem. 5:404-419; 1984.

Delistraty, D.; Hershner, C. Effects of the herbicide atrazine on adenine nucleotide levels in *Zostera marina* L. (eelgrass). Aq. Bot. 18:353-369; 1984.

Evans, A. S.; Webb, K. L.; Penhale, P. A. Photosynthetic temperature acclimation in two coexisting seagrasses, *Zostera marina* L. and *Ruppia maritima* L. Aq. Bot. 24:185-197; 1986.

Flemer, D. A.; Boynton, W. R.; D'Elia, C. F.; Kemp, W. M.; Nichols, M.; Orth, R. J.; Smollen, J. T.; Taft, J.; Wetzel, R. L. The Chesapeake Bay Program, a summary of scientific research to address management needs for Chesapeake Bay. In: Chao, N. L.; Kirby-Smith, W. eds., Proc. Internatl. Sym. Utilization of Coastal ecosystems: Planning, Pollution and Productivity, Editora da Furg, Rio Grande, Brazil. 1985; p.399-438.

Fredette, T. J.; Diaz, R. J. Life history of *Gammarus mucronatus* say (Amphipoda:Gammaridae) in warm temperate estuarine habitats, York River, Va. J. Crust. Biol. 6:57-78; 1986.

Fredette, T. J.; Diaz, R. J. Secondary production of *Gammarus mucronatus* say (Amphipoda:Gammaridae) in warm temperate estuarine habitats, York River, Va. J. Crust. Biol. 6:729-741; 1986

Goldsborough, W. J.; Kemp, W. M. Light response and acclimation for the submersed macrophyte, *Potamogeton perfoliatus* L.: implications for survival in turbid waters. Ecol. (in press).

Haramis, G. M.; Carter, V. Distribution of submersed aquatic macrophytes in the tidal Potomac River. Aq. Bot. 15:65-79; 1983.

Heck, K. L., Jr.; Orth, R. J. Seagrass habitats: the roles of habitat complexity, competition and predation in structuring associated fish and motile macroinvertebrate assemblages. In Kennedy, V., ed. Estuarine Perspectives, Academic Press, New York. 1980; p. 449-464.

Heck, K. L., Jr.; Orth R. J. Structural components of eelgrass (*Zostera marina*) in the lower Chesapeake Bay - Decapod Crustacea. Est. 3:289-295; 1980.

Heck, K. L., Jr.; Thoman, T. A. The nursery role of seagrass meadows in the upper and lower Chesapeake Bay. Est. 7:70-92; 1984.

Hershner, C. H.; Wetzel, R. L. Submerged and emergent aquatic vegetation of the Chesapeake Bay. In: Majumdar, S.; Hall, L.; Austin, H., eds. Contaminant problems and management of living Chesapeake Bay resources. Pennsylvania Acad. Sci. Typehouse of Easton, Phillipsburg, NJ. 1987; p. 116-133.

Jones, T. W.; Kemp, W. M.; Stevenson, J. C.; Means, J. C. Degradation of atrazine in estuarine water/sediment systems and selected soils. J. Env. Quality 11:632-638; 1982.

Jones, T. W.; Winchell, L. Uptake and photosynthetic inhibition by atrazine and its degradation products on four species of submerged aquatic vegetation. J. Env. Qual. 13:243-247; 1983.

Jones, T. W.; Estes, P. S. Uptake and phytotoxicity of soil-sorbed atrazine for the submerged aquatic plant, *Potamogeton perfoliatus* L. Arch. Environ. Contam. and Tox., 13:237-241; 1983.

Kahn, J. R.; Kemp, W. M. Economic losses associated with the degradation of an ecosystem: the case of submerged aquatic vegetation in Chesapeake Bay. J. Env. Econ. Manag. 12:246-263; 1984.

Kemp, W. M.; Means, J. C.; Jones T. W.; Stevenson, J. C. Herbicides in Chesapeake Bay and their effects on submersed aquatic vegetation. In: Chesapeake Bay Program technical studies: a synthesis. 1981; p. 502-558.

Kemp, W. M.; Boynton, W. R.; Twilley, R. R.; Stevenson, J. C.; Means, J. C. The decline of submerged vascular plants in upper Chesapeake Bay: summary of results concerning possible causes. Mar. Tech. Soc. J. 17:78-89; 1983.

Kemp, W. M.; Boynton, W. R.; Hermann, A. J. A simulation modeling framework for ecological research in complex systems: the case of submerged vegetation in upper Chesapeake Bay. NOAA publication, Marine Ecosystem Modeling, Proceedings from Workshop, p. 131-158; 1983.

Kemp W. M. Seagrass ecosystems as a coastal resource. Mar. Tech. Soc. J. 17:3-5; 1984.

Kemp, W. M.; Boynton, W. R.; Twilley, R. R.; Stevenson, J. C.; Ward, L. G. Influences of submersed vascular plants on ecological processes in upper Chesapeake Bay. In Kennedy, V., ed. The estuary as a filter. Academic Press, N.Y. 1984; p. 367-394.

Kemp, W. M.; Boynton, W.; Cunningham, J.; Stevenson, J. C.; Jones, T.; Means, J. Effects of atrazine and linuron on photosynethesis and growthof the macrophytes, *Potamogeton perfoliatus* L. and *Myriophyllum spicatum* L., in an estuarine environment. Mar. Env. Res. 16:255-280; 1984.

Kemp, W. M.; Lewis, M. R.; Jones, T. W. Comparison of methods for measuring production by the submersed macrophyte, *Potamogeton perfoliatus* L. Limnol. Oceanogr. 31:1322-1334; 1986.

Kemp, W. M.; Murray, L. Oxygen release from roots of the submersed macrophyte, *Potamogeton perfoliatus* L: regulating factors and ecological implications. Aq. Bot. 26:271-283; 1986.

Kollar, S. A. SAV reestablishment results. Upper Chesapeake Bay. In: Coastal zone '85. Proceedings of the Fourth Symposium on Coastal and Ocean Management. p. 759-777; 1985.

Macalister, E. G.; Orth, R. J. Chesapeake Bay's underwater forests. Sea Frontiers 20:115-121; 1984.

Murray, L.; Wetzel, R. L. Oxygen metabolism of the principal autotrophic components of a temperate seagrass community: plant-epiphyte, phytoplankton and benthic algae. Mar. Ecol. Prog. Ser. 38:231-239; 1987.

Olney, J. E.; Boehlert, G. W. Nearshore ichthyoplankton associated with seagrass beds in the lower Chesapeake Bay. Mar. Ecol. Prog Ser. (in press).

Orth, R. J. Submerged aquatic vegetation in the Chesapeake Bay: value, trends and management. In: Groman, H.; Meyers, E.; Burke, D.; Kusler, E., eds. Wetlands Conference on the Chesapeake Bay. Environmental Law Institute. Washington, D.C. 1985; p. 84-95.

Orth, R. J. Grasses beneath the bay. Virginia Wildlife 48:28-31; 1987.

Orth, R. J.; Heck, K. L., Jr. Structural components of eelgrass (*Zostera marina*) meadows in the lower Chesapeake Bay - fishes. Est. 3:278-288; 1980.

Orth, R. J.; Heck, K. L., Jr.; Diaz, R. J. Littoral and intertidal systems in the mid-Atlantic coast of the United States. In: Nienhuis, P.; Mathieson, A., eds. Ecosystems of the World - Intertidal and Littoral Systems of the World. Elsevier Sci. Publ. (in press).

Orth, R. J.; Heck, K. L., Jr.; van Montfrans, J. Faunal communities in seagrass beds: a review of the influence of plant structure and prey characteristics on predator-prey relationships. Est. 7:339-350; 1984.

Orth, R. J.; Heck, K. L., Jr.; Weinstein, M. P. Faunal relationships in seagrass and marsh ecosystems. Est. 7:273-470; 1984.

Orth, R. J.; Moore, K. A. Submerged aquatic vegetation in the Chesapeake Bay: past, present and future. In Proc. 46th North American Wildlife and Natural Resources Conference. Wildlife Management Institute, Washington, D.C. 1981; p. 271-283.

Orth, R. J.; Moore, K. A. The effect of fertilizers on transplanted eelgrass, *Zostera marina* L., in the Chesapeake Bay. In: Webb, F., ed. Proc. Ninth Annual Conference on Wetlands Restoration and Creation. Hillsborough

Community College, Tampa, FL, May 20-21, 1982; p. 104-131.

Orth, R. J.; Moore, K. A. Seed germination and seedling growth of *Zostera marina* L. (eelgrass) in the Chesapeake Bay. Aq. Bot. 15:117-131; 1983.

Orth, R. J.; Moore, K. A. Chesapeake Bay: an unprecedented decline in submerged aquatic vegetation. Sci. 222:51-53; 1983.

Orth, R. J.; Moore, K. A. Submersed vascular plants: techniques for analyzing their distribution and abundance. Mar. Tech. Soc. J. 17:38-52; 1983.

Orth, R. J.; Moore, K. A. Distribution and abundance of submerged aquatic vegetation in Chesapeake Bay: an historical perspective. Est. 7:531-540; 1984.

Orth, R. J.; Moore, K. A. Seasonal and year-to-year fluctuations in the growth of eelgrass (*Zostera marina* L.) in the lower Chesapeake Bay, Virginia, USA. Aq. Bot. 24:335-341; 1986.

Orth, R. J.; Moore, K. A. Distribution of *Zostera marina* L. and *Ruppia maritima* L. s.l. along depth gradients in the lower Chesapeake Bay, USA. Aq. Bot. (in press).

Orth, R. J.; Simons, J.; Allaire, R.; Carter, V.; Hindman, L; Moore, K.; Rybicki, N. Distribution of submerged aquatic vegetation in the Chesapeake Bay and tributaries - 1984. Final report. U.S.E.P.A. 155 p.; 1985.

Orth, R. J.; Simon, J.; Capelli, J.; Carter, V.; Hindman, L.; Hodges, S.; Moore, K.; Rybicki, N. Distribution of submerged aquatic vegetation in the Chesapeake Bay and tributaries - 1985. Final Report. U.S.E.P.A. 305 p.; 1986.

Orth, R.; Simons, J.; Capelli, J.; Carter, V.; Hindman, L.; Hodges, S.; Moore, K.; Rybicki, N. Distribution of submerged aquatic vegetation in the Chesapeake Bay and tributaries and Chincoteague Bay - 1986. Final Report. U.S.E.P.A. 191 p.; 1987.

Orth, R. J.; van Montfrans, J. The role of micrograzing on seagrass periphyton: a review. Aq. Bot. 18:43-69; 1984.

Orth, R. J.; van Montfrans, J. Utilization of a seagrass meadow and tidal marsh creek by blue crabs, *Callinectes sapidus* Rathbun. I. Seasonal and annual variations in abundance with an emphasis on post-settlement juveniles. Mar. Ecol. Prog. Ser. 41:283-294; 1987.

Rizzo, W. M.; Wetzel, R. L. Intertidal and shoal benthic community metabolism in a temperate estuary: studies of spatial and temporal scales of variability. Est. 8:342-351; 1985.

Roberts, M. H., Jr.; Orth, R. J.; Moore, K. A. Growth of *Zostera marina* L. seedlings under laboratory conditions of nutrient enrichment. Aq. Bot. 20:321-328; 1984.

Rozas, L. P.; Odum, W. E. The role of submerged aquatic vegetation in influencing the abundance of nekton on contiguous tidal fresh-water marshes. J. Exp. Mar. Biol. Ecol. 114:289-300; 1987.

Rybicki, N. B.; Carter, V. Effects of sediment depth and sediment type on the survival of *Vallisneria americana* Michx grown from tubers. Aq. Bot. 24:233-240; 1986.

Ryer, C. H. Temporal patterns of blue crab feeding in a lower Chesapeake Bay tidal marsh creek and adjacent seagrass meadow. Est. 10:136-140; 1987.

Ryer, C. H.; Boehlert, G. W. Feeding chronology, daily ration, and the effects of temperature upon gastric evaluation in the pipefish, *Syngnathus fuscus*. Env. Biol. Fish. 9:301-306; 1983.

Ryer, C. H.; Orth, R. J. Feeding ecology of the northern pipefish, *Syngnathus fuscus*, in a lower Chesapeake Bay seagrass community. Est. 10:330-336; 1987.

Shabman, L. A. Benefit taxation for environmental improvement: a case example of Virginia's soft crab industry. Land Econom. 61:398-408; 1986.

Silberhorn, G.; Orth, R. J.; Moore, K. A. Anthesis and seed production in *Zostera marina* L. (eelgrass) from the Chesapeake Bay. Aq. Bot. 15:133-144; 1983.

Stevenson, J. C.; Confer, N. M. Summary of available information on Chesapeake Bay submerged aquatic vegetation. United States Fish and Wildlife Service Biological Services Program FWS/OBS - 78/66, Washington, D. C. U.S.A.; 1978.

Steward, K. K.; Van, T. K; Carter, V.; Pieterse, A. H. *Hydrilla* invades Washington, D. C. and the Potomac. Am. J. Bot. 71:162-163; 1984.

Twilley, R. R.; Kemp, W. M.; Staver, K. W.; Stevenson, J. C.; Boynton, W. R. Nutrient enrichment of estuarine submersed vascular plant communities. I. Algal growth and effects on production of plants and associated communities. Mar. Ecol. Prog. Ser. 23:179-191; 1984.

Twilley, R. R.; Ejdung, G.; Romase, P.; Kemp, W. M. A comparative study of decomposition, oxygen consumption and nutrient release for selected aquatic plants occurring in an estuarine environment. Oikos 47:190-198, 1984.

van Montfrans, J.; Orth, R. J.; Vay, S. Preliminary studies of *Bittium varium* grazing on eelgrass periphyton. Aq. Bot. 14:75-90; 1982.

van Montfrans, J.; Wetzel, R. L.; Orth, R. J. Epiphyte-grazer relationships in seagrass meadows: consequences for seagrass growth and production. Est. 7:289-309; 1984.

Ward, L. G.; Kemp, W.M.; Boynton, W. R. The influence of waves and seagrass communities on suspended sediment dynamics in an estuarine embayment. Mar. Geol. 59:85-103; 1984.

Weinstein, M. P. Population dynamics of an estuarine-dependent fish, the spot, along a tidal creek-seagrass meadow coenocline. Canadian J. Fish. Aquat. Sci. 40:1633-1638; 1983.

Weinstein, M. P.; Brooks, H. A. Comparative ecology of nekton residing in a tidal creek and adjacent seagrass meadow: community composition and structure. Mar. Ecol. Prog. Ser. 12:15-25; 1983.

Wetzel, R. L.; Penhale, P. A. Production ecology of seagrass communities in the lower Chesapeake Bay. Mar. Tech. Soc. J. 17:22-31; 1983.

Wetzel, R. L.; Neckles, H. A. A model of *Zostera marina* L. photosynthesis and growth: simulated effects of selected physical-chemical variables and biological interactions. Aq. Bot. 26:307-324; 1986.

Zieman, J. C.; Orth, R.; Phillips, R.; Thayer, G.; Thorhaug, A. The effects of oil spills on seagrass ecosystems. In Cairns, J.; Buikema, A., eds. Restoration of habitats impacted by oil spills. Butterworth Publ. Mass. 1984; p. 37-64.