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Project Summary

Submerged Aquatic Vegetation in Upper Chesapeake Bay: Studies Related to Possible Causes of the Recent Decline in Abundance

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This study synthesizes research conducted on possible causes of the decline in abundance of submerged aquatic vegetation (SAV) in upper Chesapeake Bay beginning in the late 1960's. Three factors potentially were emphasized in this study: runoff of agricultural herbicides; erosional inputs of fine-grain sediments; nutrient enrichment and associated algal growth. Widespread use of herbicides in the estuarine watershed occurred contemporaneous with the SAV loss, but extensive sampling of estuarine water and sediments during 1980-81 revealed that typical bay concentrations of herbicides (primarily atrazine) rarely exceeded 2 ppb. However, normal concentrations (< 5 ppb) were shown experimentally to have little measurable effect on plants. Increases in turbidity have been documented for some bay tributaries since the 1940's. Light (PAR) attenuation by suspended fine-grain sediments contributed more to total turbidity in bay shallows (< 1.5m) than did phytoplankton chlorophyll *a*. Evidence indicated that plant photosynthesis was light-limited for much of the day. Effects of the continual increase in nutrient enrichment of the bay (documented since 1930) were tested by experimentally fertilizing pond mesocosms at levels common to the upper estuary. Moderate to high nutrient loadings resulted in significant increases in growth of epiphytic and planktonic algae and decreases in SAV production.

This Project Summary was developed by EPA's Chesapeake Bay Program, Annapolis, MD, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

It is widely recognized that submerged vascular plants play an important role in the ecology of littoral regions of lakes, estuaries and oceans. While a number of studies have noted the ability of these plant communities to attenuate variability of nutrient, sediment and production cycles, several such communities have themselves undergone extreme fluctuations in distribution and abundance. For example, in the mid 1930's a widespread die-off of the seagrass, *Zostera marina*, was well documented throughout the North Atlantic coastal regions. The cause of this occurrence has never been unequivocally established, although recent suggestions have pointed to subtle climatic shifts. Other reports of regional declines in abundance of submerged aquatic vegetation (SAV) have indicated the possible influence of human activities.

Few of the reported SAV declines have occurred in estuarine environments and most have involved 1 or 2 plant species

However, in one of the world's largest estuaries, Chesapeake Bay, a major loss of SAV has continued from the mid 1960's to the present. More than 10 species have experienced significant decreases in abundance, including *Potamogeton perfoliatus, P pectinatus, Valisneria americana, Zannichellia palustria, Ruppia maritima* as well as the marine species *Z. marina.* In the upper estuary this decline in native species was preceded by an invasion of the exotic *Myriophyllum spicatum,* which eventually also died back. Studies of seed and pollen distribution in sediment cores from the upper bay have demonstrated that this diminution in plant abundance is unprecedented for at least the last century In general, it appears that the recent decline occurred first and with greatest intensity in the brackish waters of the estuary, with *Z. marina* communities in the lower bay being affected less and somewhat later.

Numerous mechanisms have been cited as possible causes of this occurrence The concept that natural entrained population cycles or global climatic events might be responsible seems unlikely in view of the range of biological and physiological characteristics for the numerous species involved In addition, there is no parallel trend in plant abundance apparent in nearby coastal regions. Other factors including animal foraging and grazing and major storm events are probably of occasional and local importance, but these are part of the normal milieu to which SAV are exposed and hence are insufficient to explain this abnormal decline. The absence of correlations between distribution of SAV and industrial pollutants renders such anthropogenic wastes an unlikely cause; however, more general changes in water quality associated with diffuse sources (e g , runoff) do represent a potential explanation These include increased fine-grain sediments from land erosion, increased algal growth from nutrient enrichment of estuarine waters, and aqueous concentrations of herbicides arising from agricultural runoff

The full report presents results of research conducted at the University of Maryland's Center for Environmental and Estuarine Studies concerning factors potentially involved in the decline of submerged aquatic vegetation in upper Chesapeake Bay. The research examines three main factors in relation to SAV growth and production. agricultural herbicides, suspended sediments and associated light attenuation, nutrient enrichment and resulting algal growth and light attenuation.

Approach and Methodology

In 1978 we initiated a 4-year study to investigate various aspects of the ecology of SAV communities in Chesapeake Bay. While intensive research was conducted at several locations along the estuarine salinity gradient, our work focussed on communities located in the low salinity (5-15°/oo) region. The research considers factors potentially responsible for the observed decline in SAV distribution and abundance. It was organized in a hierarchical fashion with both mechanistic and holistic experiments combined in a sequence of systems and subsystems to deal with the complexity of the ecosystems studied in addressing these questions.

Herbicide concentrations were measured in the field to describe both long-term mean levels and short-term responses to storm/runoff events Phytotoxic effects of these compounds on SAV photosynthesis, growth and vegetative reproduction were examined in various experimental systems ranging in size from 1-500 l and in duration from hours to months. Photosynthesis was estimated as O_2 production, and ^{14}C incorporation and growth as increases in number and biomass of shoots and other plant material Degradation, sorption, and plant uptake of atrazine were measured using ^{14}C ring-labelled compounds.

Nutrient enrichment studies were done using 500 m^3 experimental ponds filled and flushed with estuarine water and planted with SAV from the Choptank River estuary Plankton, epiphyte, and SAV biomass were measured at 1-4 wk intervals throughout the growing season Light attenuation due to epiphytes was measured as reduction in transmittance through clear acrylic slides covered with various levels of algal growth. Nutrient levels in water, sediments, and plant material were also analyzed periodically using standard techniques. Parallel experiments were done in 75 l laboratory microcosms having short (30 cm) water columns to minimize the effect of phytoplankton.

Data from these and other experiments were analyzed for inclusion in numerical models to simulate ecosystem behavior. These models were calibrated and verified with separate data sets to produce models that behaved consistently with nature Model computations were done using digital computers; experiments were performed by changing one or more external factors to simulate various spatial and temporal conditions.

Results and Conclusions

Herbicides

Considerable effort was expended to investigate the potential importance of herbicides in contributing to the overall stress of the estuary's SAV populations. This research emphasized two specific compounds. The first of these, atrazine, which is closely associated with corn crops, has been the most widely used herbicide in the region, and the second compound, linuron, is commonly employed in weed control for soybeans. Concentrations of these two herbicides were monitored in water and sediments throughout the upper bay over the period 1980-81. A hierarchically designed stratified sampling scheme revealed typical aqueous concentrations of both compounds to be about 0-3 ppb in the main bay, 0-5 ppb in a major eastern shore tributary, and 0-40 ppb in a creek connecting a small estuarine cove to surrounding agricultural fields. Concentrations in the creek and small cove were measured at 1-4 h intervals before, during, and after all runoff events, and values above 5 ppb never persisted for more than 6-8 h. Atrazine concentrations associated with suspended or deposited sediments were less than 5 ppb for >95% of samples and never exceeded 20 ppb

Initial studies indicated a wide range of physiological and morphological responses of one common SAV species, *Potamogeton perfoliatus*, in response to herbicide treatment, including photosynthetic depression, stem elongation, reduction in stem weight per unit length, and increased chlorophyll *a* per unit leaf area. Several of these effects are analogous to observed adaptations of this and related species to reduced light intensity.

At atrazine or linuron concentrations between 5-100 ppb, significant photosynthetic inhibition was observed for both *P. perfoliatus* and *Myriophyllum spicatum* in microcosms, followed by strong recovery (toward untreated control plants) within 1-3 wk, even though herbicide levels remained within 5-10% of initial values throughout Plant biomass decreased significantly after 5 wk of treatment at herbicide concentrations > 50 ppb for *P. perfoliatus* and >500 ppb for *M. spicatum.* Overall, the effects of the two herbicides were statistically identical, while some differences between plant species were observed (*M. spicatum* being more tolerant) Estimates of I_{10} (herbicide concentration at which 1% loss of photosynthesis [P_a] is predicted) were 2-4 ppb for *P perfoliatus* and 8-11 ppb for *M. spicatum*, and values of I_{50} (concentration for 50% loss of P_a) ranged from 45-55 ppb and 80-117 ppb, respectively Similar phytotoxicities were observed for *Zannichellia palustria* and *Ruppia maritima*.

Rapid uptake of ^{14}C-labelled atrazine was demonstrated for *P. perfoliatus*, with equilibrium between internal and external concentrations being achieved within about 1 h A direct relation between atrazine uptake and photosynthetic depression was observed for this plant, however, disproportionately high apparent uptake at low external herbicide concentrations suggest a two-step uptake process with simple sorption (without inhibition of photosynthesis) dominating at low concentrations Root uptake of atrazine appears to be of little importance for these plants. Initial photosynthetic recovery of atrazine-treated plants was affected by release of sorbed herbicide within 2 h after rinsing in atrazine-free water Some loss of photosynthesis (~ 5%) was evident after 3 d of wash, however, this difference was not statistically significant Short-term (2 h) experimental exposures to atrazine revealed reductions in *P. perfoliatus* photosynthesis which were similar to those observed over 2-6 wk in microcosms, with values of I_{50} being about 80 ppb.

Atrazine is readily sorbed to soil and sediment particles, with a partition coefficient (sorbed·aqueous) greater than 1.0 However, the potential importance for plant uptake of atrazine sorbed to overlying sediments (resting on SAV leaves) seems to be remote Experiments with ^{14}C-labelled atrazine showed negligible plant uptake of herbicide sorbed to soils at concentrations of about 120 ppb In addition, the presence of epiphytic sediments significantly retarded leaf uptake of aqueous atrazine, although such sediments themselves inhibited photosynthesis presumably by attenuation of light and reduction of CO_2 uptake

The degradation of ^{14}C-labelled atrazine was observed under simulated field conditions for upper and middle bay sediment-water systems and for two common agricultural soils in the Maryland coastal plain. The distributions of atrazine and two categories of metabolites or degradation products (hydroxyatrazine and dealkylated atrazine) were followed over an 80 d period The half-life (time for 50% degradation to metabolites) for atrazine was markedly shorter for estuarine systems (15-20 d) than for soils (330-385 d). The accumulation of hydroxyatrazine in experimental estuarine water and sediments raised questions concerning the potential phytotoxicity of these compounds Bioassay experiments were performed with 4 species of SAV to examine uptake and photosynthetic depression for ^{14}C-labelled atrazine and 3 metabolites. Overall, the inhibitory effect of the metabolite, hydroxyatrazine, on plant photosynthesis was negligible compared to that for atrazine, with no significant inhibition even at 1500 ppb. Some significant loss of P_a was observed for deethylated atrazine at 500 ppb ; however, this metabolite has a short half-life in the estuary, being similar to that for atrazine.

Nutrients, Sediments and Light

The effects of nutrient enrichment on algal (planktonic and epiphytic) growth and SAV production and abundance were investigated by fertilizing 8 (duplicates at 4 levels) experimental ponds (500 m^3) during June-August 1981. These ponds, which were seeded with sediment, water and plants from the Choptank River estuary, were maintained in batch mode for sequential periods of 7-10 d punctuated by complete exchange of water followed by retreatment prior to the next batch period Maximum fertilization rates were typical of nutrient loading in areas of upper Chesapeake Bay receiving direct agricultural runoff. Nutrient concentrations in treated ponds were reduced rapidly to control levels within 1-3 d, and plant tissue nutrient contents were directly related to treatment. Initial growth of the two dominant SAV species (*P. perfoliatus* and *R. maritima*) was enhanced in fertilized ponds, however, plant abundance in August was inversely related to treatment, with SAV virtually eliminated at the highest dosage

Planktonic and epiphytic algal biomass (as chlorophyll *a*) increased significantly with treatment Light (PAR) attenuation by microalgae was sufficient to account for the reduction in SAV production and abundance in August Epiphytic growth accounted for most of the light reduction, although attenuation in the water column was also necessary to reduce PAR below plant compensation levels Field observations indicated that inorganic sediments could comprise as much as 80% of the total mass of material accumulated on SAV leaves, but these inorganic particulates appear to be directly associated with growth of epiphytic organisms. Direct measurements of epiphyte effects on both PAR attenuation (by leaf scrapings in petri dishes) and plant photosynthesis (with ^{14}C-labelled bicarbonate) confirmed this relationship.

A second year (1982) of fertilization in the experimental ponds provided a more detailed examination of the nutrient-algal-SAV relationships Problems encountered in the batch-mode approach in 1981 were alleviated with a continuous flow system and more frequent treatment In this 1982 study only 4 ponds were used, and SAV communities in these were essentially mono-specific stands of *P. perfoliatus*, thus eliminating the complicating problems of differential epiphytic colonization on 2 SAV species The general patterns observed in 1982 were more pronounced and consistent than in the 1981 research. Preliminary evidence suggests that a shortening of SAV growing season, as observed here in response to fertilization, may ultimately lead to decimation of these plant populations by disrupting plant reproduction Light attenuation by microalgae and suspendable sediments may affect the normal balance between SAV production and respiration, leading to premature flowering and/or insufficient translocation to underground propagules, both of which would reduce the viability of regrowth in the following spring. It is concluded that further research is needed to understand the reproductive capacities and strategies for these plants

In nature, due to sediment resuspension by tides and storms, turbidity levels can increase rapidly by factors of 3 and 10, respectively. Therefore, detailed studies of the responses and adaptations of *P perfoliatus* to direct treatments of various light levels (high 100%, medium 34%, low 6%) were also done in 1982 Numerous morphological and physiological changes in this plant were observed in response to reduced (moderate and low) light, including stem elongation, increased pigmentation, increased specific leaf area, as well as increased initial slope of photosynthesis versus irradiance relations Most of these adjustments appear to confer adaptive advantage on shaded plants, however, after 2 wk of exposure to low light, significant reductions in stem density, flowering, and underground reproductive propagules were observed

Conclusions

The relative contributions of herbicide runoff, sediment loading and nutrient enrichment to the environmental stress experienced by SAV in upper Chesapeake Bay were considered with integrative approaches. Combining these research findings in a conceptual framework as well as a numerical simulation model suggested that the relative importance of effects on SAV associated with these 3 inputs is as follows: nutrients > sediments >> herbicides. Historical data suggest that SAV declines over the past several decades occurred earliest in the upper bay and tributary rivers and progressed downstream towards the main bay. Such a pattern is consistent with factors found to stress SAV, as it is in the upper reaches of these estuaries, where water quality declined earliest and waste loadings are most intense. In terms of SAV rehabilitation, it appears that reductions in nutrient loading would be the most advisable strategy, since excessive nutrients severely stress these communities and because nutrient control measures are available and effective. It may also be advisable to consider transplanting programs to accelerate recovery in areas where water quality is adequate, but such activities should be coordinated with efforts to better understand the reproductive biology of SAV to increase the probability of success.

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The complete report, entitled "Submerged Aquatic Vegetation in Upper Chesapeake Bay: Studies Related to Possible Causes of the Recent Decline in Abundance," (Order No. PB 84-140 292; Cost: $26.50, subject to change) will be available only from:

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