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Submerged Aquatic Vegetation in Delaware's Inland Bays

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TABLE OF CONTENTS

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INTRODUCTION

Submerged aquatic vegetation (SAV) is an important living resource in many coastal areas throughout the world. These plant communities have been cited as some of the most biologically important in the world (McRoy and Helfferich, 1977; Stevenson and Confer, 1978; Phillips and McRoy, 1980) for the following reasons:

1. They provide habitat for numerous species of vertebrates and invertebrates that occur in or over the plant canopy, on the blades of vegetation or in the sediment surrounding the vegetation. Densities of animals in vegetated areas can be orders of magnitude greater than in nearby, unvegetated areas. Many of these smaller organisms serve as a source of food for larger invertebrates, fishes or waterfowl.

2. The plants themselves can serve as food for waterfowl.

3. The plants bind sediments and reduce current velocities, thus stabilizing the bottom, and in areas with very dense beds, reduce shoreline erosion.

4. SAV, with their attached micro- and macroalgae, have extremely high rates of primary production that rival many cultivated crops.

5. Most of this primary production is eventually exported from the bed and enters the detrital food pathway, thus serving a biological community far removed from the existing bed.

6. SAV can remove nutrients from the water column, thus reducing ambient levels, and can pump nutrients from the sediment to the leaves, releasing nutrients to the surrounding water, increasing ambient concentrations.

There are numerous species of SAV with a generally higher diversity found in freshwater as compared to marine areas. Worldwide there are only 50-60 species of SAV that tolerate saline conditions (>15 ‰) (den Hartog, 1970). Along the mid-Atlantic coast of the United States, only two species, eelgrass (Zostera marina) and widgeongrass (Ruppia maritima), are dominant in saline areas compared to six species found in the warmer Florida and Gulf of Mexico areas (Zieman, 1982; Thayer et al., 1984). These two species can be found in both mono-specific as well as mixed stands. In the Chesapeake Bay, eelgrass has been found to be dominant generally in water depths of greater than one meter below mean low water (MLW) while widgeongrass has been found dominant in water depths less than 0.25 m below MLW. Both species are found in mixed beds at intermediate depths (Orth et al., 1979).

SAV most commonly occur in the shallowest areas of coastal estuaries, lagoons or bays. Available light penetrating the water column is one important, and usually limiting, factor regulating the depth distribution of any SAV species. In the water column, light is attenuated with depth by adsorption and scattering due to the water itself as well as dissolved and particulate matter in the water. The dissolved and particulate matter are, in turn, influenced by a number of factors such as runoff of silts and clays from the upland, resuspension of bottom sediments by wave action, bioturbation and biodeposition and phytoplankton levels regulated to some degree by nutrient levels and nutrient regeneration rates (Kemp et al., 1983). Light can also be attenuated on the leaves of the plants themselves through the growth of epiphytic plant and animal communities (Sand-Jensen and Borum, 1984) which are regulated, in turn, by the supply of nutrients, as well as the rate at which these attached communities are grazed by larger organisms (Orth and van Montfrans, 1984; van Montfrans et al., 1984). At high densities, epiphytes can also act as a boundary layer limiting the exchange of dissolved gases necessary for photosynthesis (Sand-Jensen, 1977). Thus, depth distribution of some species of SAV in very clear tropical waters or oligotrophic lakes can be 50 meters or more. In normally turbid, estuarine or lagoonal environments, light penetration is substantially reduced and so are the depths to which SAV are found. In the Chesapeake Bay, SAV are not found in water depths greater than two meters below MLW and are most common in water depths of one meter or less below MLW (Orth and Moore, 1981, 1984).

Because SAV grow in shallow water environments, they are very susceptible to disturbances, biological (e.g. uprooting by cownose rays), climatological (e.g. hurricanes), or man-induced, either directly (e.g. damage by boat propellers, dredging or filling) or indirectly (e.g. increased nutrient or sediment inputs from improper sewage treatment facilities or land use practices).

Dramatic, natural shifts in SAV abundance have been characteristic of SAV populations along the east coast. Episodic explosions of water chestnut (Trapa natans), Eurasian watermilfoil (Myriophyllum spicatum) and hydrilla (Hydrilla verticillata) in the Chesapeake Bay have been well documented in the past 80 years (Orth and Moore, 1981, 1983a, 1984). The most documented natural alteration of any species of SAV occurred with the worldwide decline of eelgrass in the early 1930's. Eelgrass populations along its entire range on the east coast of the U. S. from North Carolina to Canada and the west coast of Europe were dramatically altered in the span of several years (Cottam and Munro, 1954; Rasmussen, 1977). Initially, a pathogen, Labyrinthula spp., was suspected as the causal agent. Later, an hypothesis relating climatic changes to this decline became more acceptable. Populations in most areas subsequently returned at various rates of recovery where levels of abundance by the 1950's and 1960's were similar to populations present prior to the decline. Some areas along the east coast never recovered, however, including many of the bays behind the barrier islands along the Delmarva peninsula (Cottam and Munro, 1954; Orth and Moore, 1984).

Associated with the large decline of eelgrass in the 1930's were major changes in the animal communities that were closely tied to the presence of this vegetation (Stauffer, 1937; Rasmussen, 1977). For example, scallop and waterfowl populations, which are heavily dependent upon eelgrass as a settling substrate or for food, respectively, were markedly reduced (Orth, 1978; Perry et al., 1981).

Eutrophication or increased nutrient enrichment of coastal waters has been often cited as a primary factor responsible for the declining populations of seagrasses as well as freshwater submerged vascular plants in Europe, Asia, North America and Australia (den Hartog and Polderman, 1975; Peres and Picard, 1975; Kemp et al., 1983; Orth and Moore, 1983a; Cambridge and McComb, 1984; Lewis et al., 1985). Increased water column nutrients result in the rapid growth of two very distinct groups of smaller plants, phytoplankton and epiphytes, that can both shade or foul the seagrass leaf surface (Bulthius and Woelkerling, 1983; Borum, 1985; Twilley et al., 1985). However, the negative effects attributed to either phytoplankton or epiphytes may be highly variable. Much of the published literature to date indicates that epiphytes stimulated by increased nutrients either from a point or non-point source, rather than phytoplankton, are, in many marine areas, a major factor in the decline of submerged macrophytes (Phillips et al., 1978).

Decline of seagrasses can be rapid, occurring in one to two years, or may take many years. Where declines have been shown to take many years, losses of seagrasses first occurred in the deeper sections of the bed. This would be expected since light reaching the plant surface under optimal conditions decreases with increased depth of the bed. The deeper, outer limits of seagrass beds are, in most cases, light limited and any reduction in light caused by sediment, phytoplankton or epiphytes would affect those plants already light-limited. Orth et al. (1979) showed that declines of the seagrass Zostera marina in one section of the Chesapeake Bay first occurred in the deeper, offshore sections of the bed during a ten year time span. Sand-Jensen and Borum (1984) found the depth limitation of Lobelia dortmanna, a fresh water SAV species, to be 1.0 m, but without epiphyte attenuation, the daily light compensation depth in the spring was 3.5 m. They suggested that epiphyte attenuation is important in the seasonal growth and depth penetration of macrophytes. Not only does this phenomena occur with seagrasses, but Kautsky et al. (1986) showed that the macroalga Fucus vesiculosus changed its depth distribution in the Baltic Sea over a period of 40 years in response to increased eutrophication. The lower limit of growth decreased from 11.5 m to 8.5 m while the zone of maximum development decreased from 5-6 m to 3-4 m during this time period.

Although much emphasis has been placed on the declines of submerged aquatic vegetation because of eutrophication, two studies document the return of vegetation following improvements in water quality. These two studies have particular relevance in that they indicate that submerged vegetation can rapidly recover in some situations when water quality improved. Nienhuis and De Bree (1977) and Nienhuis (1983) followed the distribution patterns of Zostera marina in the Grevelingen estuary in the Netherlands following the closure of the estuary by a dam. Because tidal circulation was stopped, the estuary became primarily influenced by wind-driven currents and water transparency substantially improved. Suspended sediment fluctuated between 0 and 100 mg/L before closure to 0-30 mg/L after closure. Transparency of the water measured by secchi readings changed from 1-2 m before closure to 4 m after closure. Nitrogen concentrations decreased dramatically after the closure while phosphorus increased mainly due to the mobilization from the sediments. After closure, the intertidal populations of Zostera marina extended to 5 m below the surfacel; the lower limit was 7.5 m.

The second example is from the Potomac River, Maryland. Prior to 1981, there were no recorded populations of SAV in the tidal freshwater portion of the river since the 1920's. In 1982 and subsequent years, substantial populations of vegetation have been found in this section in increasing abundance each year (Orth et al., 1985, 1986). The cause for the increase may be related to nutrient changes in this part of the river. There has been a dramatic decrease in phosphorus loading from the Blue Plains sewage treatment plant (the largest treatment plant in this region, handling all the raw sewage from the metropolitan Washington, D. C. area) since the late 1970's. In 1983, Blue Plains began nitrification, changing the predominant nitrogen species in the river from ammonia to nitrate. At the same time, Blue Plains reduced the suspended solids output from the plant from 4.2-9.8 mg/L in 1982 to 1.0-1.3 mg/L in 1983. Secchi depths in the upper tidal river were significantly higher in 1983 (approx. 86 cm) than in the 1978-1981 period (approx. 52 cm). Plant populations continue to increase and reached even higher levels of abundance in 1985 (Orth et al., 1986).

In addition to nutrients, light penetration can also be affected by suspended sediment. Sediment sources can be direct, from dredge or fill operations, or indirect, from improper land use practices. Both sources increase water column turbidity which has a similar affect on seagrass productivity as nutrients described above. Control of the direct sources may be less difficult than indirect sources. The latter may require long term, expensive land use management practices which, in some cases, may necessitate legal regulation of land based activities and firm enforcement of existing sediment and erosion control laws.

PRESENT AND HISTORICAL DISTRIBUTION OF SAV IN REHOBOTH BAY, INDIAN RIVER BAY AND INDIAN RIVER

SAV distribution can be determined by ground or aerial surveys. In aerial photography, SAV may show up as distinct, dark areas adjacent to land or shallow, lighter toned, unvegetated areas. This allows SAV to be photographed and mapped, resulting in a quantitative delineation of their distribution in a given area. Aerial photographs require ground truth information because submerged features such as macroalgal stands or rocks exhibit similar signatures as SAV. Aerial photography of SAV beds has distinct limitations and, if flown at inappropriate times of the day or season, can result in an underestimate of abundance. Guidelines for acquiring accurate imagery of SAV should incorporate conditions for sun angle, tidal height, cloud cover, wind, time of day and season (usually coinciding with periods of maximum SAV standing crop). Under the appropriate conditions, aerial photography, in conjunction with some level of ground information, can be a very effective mechanism for assessing distribution of SAV in most areas (Orth and Moore, 1983b).

SAV presence or absence in the Indian River, Indian River Bay and Rehoboth Bay (as well as Little Assawoman Bay) was initially determined on July 13, 1985, by field checking numerous shallow water sites that potentially could have supported SAV. This survey resulted in no rooted SAV being found. A few plants, widgeongrass, were found floating in Little Assawoman Bay but these may have resulted from irregularly flooded ponds where widgeongrass commonly occurs. Because of these findings, it was concluded that an aerial photographic mission was not necessary. A second intensive survey was conducted on August 7, 1986, at sites visited in 1985, as well as several additional areas, especially around Indian River Inlet, where anecdotal information and historical photography indicated that SAV formerly had occurred. As in 1985, no SAV was found at any sites in Rehoboth Bay, Indian River and Indian River Bay. A small but dense bed of widgeongrass was found growing in a small, non-tidal pond on what appeared to be a dredge spoil island on the western shore of Rehoboth Bay. The results of these two recent surveys indicate that SAV is not present in the Rehoboth Bay and Indian River systems today.

Although SAV reports both in the literature and from local residents suggest SAV may have previously occurred, none of these reports indicated precise distributional limits. Historical photography is one technique for examining more precisely the past limits of SAV at any specific location. However, limitations occur in the actual use of these photographs for two reasons:

1. Most aerial photography was obtained in flights undertaken for a different purpose and flights were not subject to guidelines necessary for accurate delineation of SAV beds, e.g. mid-day sun glint on the water obscures SAV, seasons when SAV standing crop are very low (early spring or late fall) or on clear, but windy days where the wind stirs the bottom creating very turbid water conditions obscuring SAV from the air.

2. There is usually no ground truth information associated with the photography to confirm whether many of the dark images were actually SAV. Delineation of permanent SAV beds compared with seasonally, and usually spatially, variable macroalgal beds, sometimes can best be determined through annual, aerial photographic surveys conducted around the same time each year, under similar environmental conditions with accurate ground truth surveys.

Given the above limitation, although an area may have adequate and regular aerial coverage, much of it may be unusable. However, careful inspection and use of only appropriate photographs for SAV mapping can provide documentation on historical changes in SAV distribution. Indeed, historical photography provided detailed data on changes in SAV populations in the Chesapeake Bay (Orth et al., 1979; Orth and Moore, 1981, 1983a, 1984).

References to SAV presence, specifically in Rehoboth Bay, Indian River and Indian River Bay, in the early 1900's were not found. One publication indicated the abundance of eelgrass in Isle of Wight and Assawoman Bays in the 1920's (Cottam, 1935), two bays just south of Delaware's Inland Bays, both being very similar in depth and morphology. Cottam and Munro (1954) reported no known stands of eelgrass in Delaware in the 1950's especially in the Indian River where it had formerly occurred. These references indicate that eelgrass was probably very abundant throughout Indian River, Indian River Bay and Rehoboth Bay in the 1920's. Anecdotal information from old-time residents indicated that dense beds of vegetation were indeed present in these bays in the 1920's.

SAV in the Delaware Inland Bays subsequently declined in the 1930's (specifically in 1931 and 1932). This decline was related to the major eelgrass decline that occurred along the east coast at this time (see above). Whether any eelgrass remained immediately after this period cannot be determined from currently available information but it is likely that small, remnant beds may have remained in some areas and were overlooked in subsequent surveys. Photography available of this area in 1937 (taken by the U.S. Department of Agriculture) revealed no apparent SAV beds although very small patches (<2 m) sometimes are not readily seen in these photographs. Similar photography taken during 1937-1938 of the Chesapeake Bay did show SAV throughout the lower bay area in different densities, indicating that some eelgrass survived the 1930's decline. Photography available from 1942 (Defense Intelligence Agency) revealed what appeared to be SAV near the Indian River Inlet. Ground truth data are not available for this period. However, the photography taken in July and August, 1954, revealed distinct areas at the Inlet (Figs. 1 and 2). These were most probably eelgrass, or eelgrass and widgeongrass, and corroborate comments by a local resident of the abundance of eelgrass in this exact area in the 1950's. This information contradicts Cottam and Munro's report (1954) of no eelgrass in Indian River.

Attempts were apparently made to transplant eelgrass into the Indian River area (Cottam and Munro, 1954) but there are no data as to the location and date of the plantings, where plants came from, how they were planted and their eventual success or failure. It is possible that some of the eelgrass planted may have survived and grew into larger areas evidenced on the photographs. It is also possible that the eelgrass present here in the 1950's was the result of growth of small beds that survived the 1930's decline.

Aerial photographs available for 1960 showed no apparent SAV in these areas. Subsequent photography in the 1970's and 1980's revealed the continued absence of any SAV. Some of the photography from the 1970's and 1980's revealed dark patches along some of the shoreline in Indian River Bay and Rehoboth Bay. These are areas that did not show evidence of SAV in the 1954 photography so it is more probable that they are large stands of macroalgae. Their high density images are quite different compared to the mottled images many SAV beds exhibit on aerial photographs. Consultation with Dr. V. Klemas of the University of Delaware's Center for Remote Sensing, and one who has also reviewed aerial photographs from the 1960's and 1970's, indicates that the dark images present on the photographs probably reflect the presence of macroalgae rather than seagrass.

The changes observed in the photography from the 1950's to 1960's parallel the anecdotal information from one long time local resident who now owns and operates Murray's Bait and Tackle shop on White Creek. A personal interview with him in August, 1986, provided an enlightening insight into the changes that occurred in the SAV population but also with the associated animal community, particularly the blue crab. He recalls eelgrass being very abundant in the 1950's in areas observed in the 1954 photography. He recalled a large storm in 1960 after which much of the eelgrass was lost (possibly being covered by sand).

The most vivid comments from the local resident pertained to the crabbing he did around the SAV beds. He distinctly remembered catching a bushel of hard crabs in a few hours and many soft crabs. When the SAV was lost (and continuing through today), crab catches were never as high (when he gets out). These observations tend to confirm much of the on-going research on blue crabs in Chesapeake Bay eelgrass beds, indicating the importance of eelgrass to juvenile and soft shell crabs.

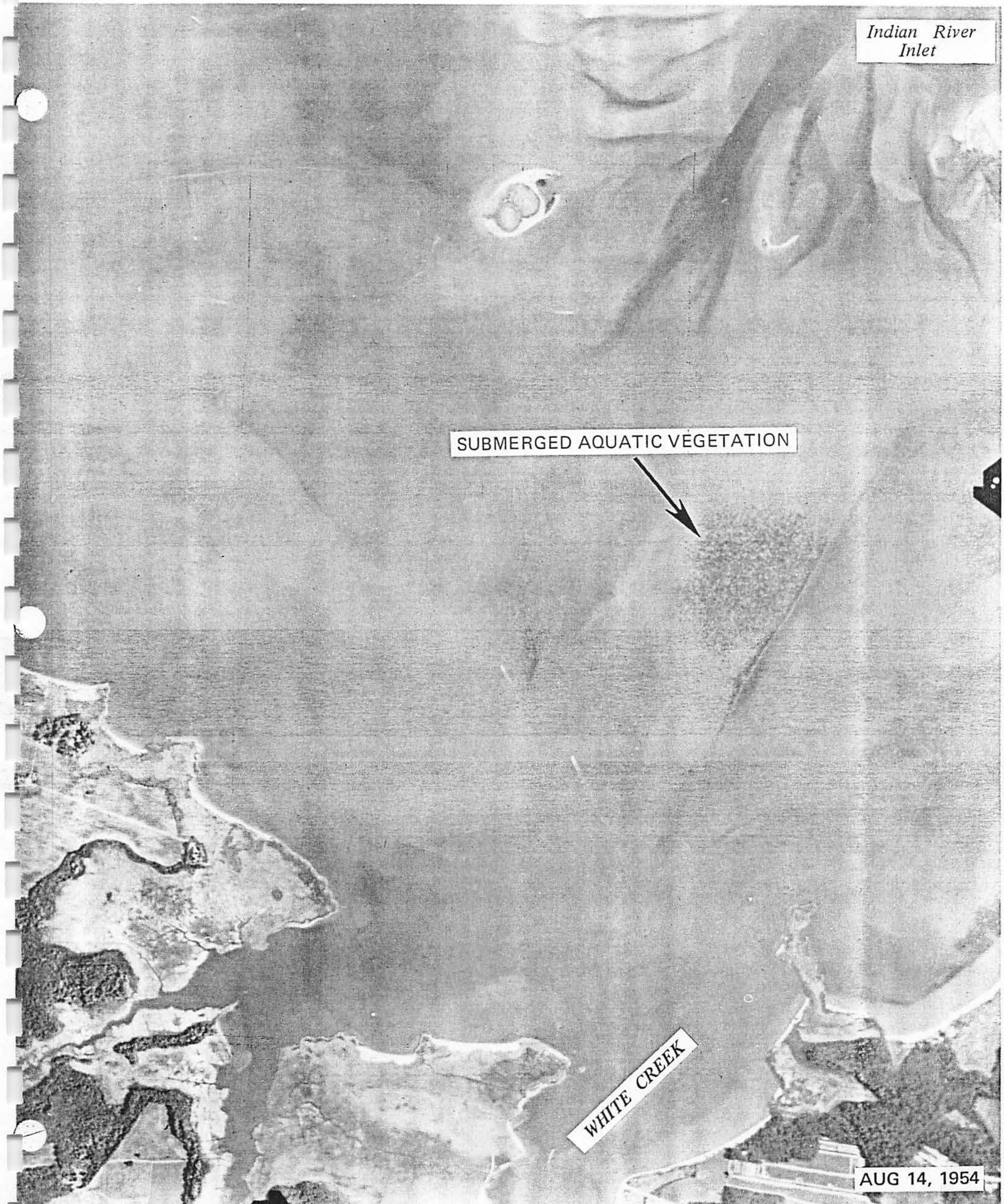
Additional anecdotal information for SAV presence comes from a University of Delaware geology professor (Dr. John Kraft) who conducted class field trips in the Delaware Inland Bays beginning in the late 1960's. His recollections are of abundant SAV growth in the eastern and southeastern portions of the bays, the areas closest to the inlet where water quality would be more optimal for SAV growth.

In summary, SAV beds were probably quite common throughout Indian River, Indian River Bay and Rehoboth Bay prior to the early 1930's. Much of the vegetation was lost during the pandemic eelgrass demise of 1931-1933. Some recovery occurred in the next 20 years. SAV was abundant in some sections by the

Figure 1. Aerial photograph taken on July 20, 1954, showing stands of aquatic vegetation along the western shore of Indian River Bay between Indian River Inlet and Pasture Point.


SUBMERGED AQUATIC VEGETATION
Pasture Point
Beach Cove
JULY 20, 1954

Figure 2. Aerial photograph taken on August 14, 1954, showing a large patch of submerged aquatic vegetation just south of the Indian River Inlet in Indian River Bay. This is the same large patch seen in the photograph taken on July 20 in Figure 1.


Indian River Inlet
SUBMERGED AQUATIC VEGETATION
WHITE CREEK
AUG 14, 1954

mid- to late 1950's and 1960's. Most, if not all SAV, was lost in the 1960's and completely gone by the early 1970's. No eelgrass or any other SAV species has been observed in the Delaware Inland Bay area in the last 15-20 years.

ENVIRONMENTAL FACTORS CONTROLLING GROWTH OF SAV: A COMPARISON OF DELAWARE'S INLAND BAYS AND CHESAPEAKE BAY

Evidence presented in the previous section indicated the presence of SAV in the 1950's, likely from recovery from the pandemic decline of the 1930's, or from the transplanting efforts of Cottam and Munro (1954). These populations declined from 1960-1970 and have never recovered. The question arises as to whether the present lack of vegetation is currently due to unsuitable environmental conditions.

Current data suggests that light and temperature are the primary determinants of SAV growth in the lower Chesapeake Bay (Wetzel and Penhale, 1983) and it is likely that these two factors may also limit SAV growth in the Delaware region, provided sites meet the appropriate limits of salinity, depths, sediment type, wave energies, etc. Temperature acts as a physiological control on enzymatically regulated processes, like photosynthesis and respiration, and, as such, regulates the geographic distribution of a species. Eelgrass, for example, reaches the southern limit of its range in North Carolina and is stressed by the high summertime water temperatures (>25°C) common in the mid-Atlantic region (den Hartog, 1970). Submarine irradiance is a primary determinant of the photosynthetic rate at levels below light saturation (Dennison, 1987).

The Virginia Institute of Marine Science (VIMS) has been involved in SAV research in the Chesapeake Bay since 1978. This program evolved because of the large scale, unprecedented, baywide decline of all species of SAV (Orth and Moore, 1981, 1983a, 1984). In recognition of the magnitude of this decline and its importance to the bay ecosystem, a baywide effort to study SAV biology and ecology was initiated (EPA, 1982).

A major, ongoing program for the last three years at VIMS has been comparing water quality parameters in the York River estuary at sites that currently support SAV and never experienced a major decline in the 1970's, to sites that formerly, but no longer, support vegetation. We have chosen this system as a model for comparison with Delaware's Inland Bays. We believed this would provide a "model" for determining whether levels of various parameters important for SAV (principally eelgrass) growth and survival in the Delaware system are within the range of values presently found for SAV beds in the York River.

Three sites located along an upstream gradient in the York River estuary in Virginia (Fig. 3) have been chosen for comparison with four sites monitored in the Delaware Inland Bays program (Fig. 4) for the period from September,1985 to September,1986. Sampling was undertaken approximately biweekly in the York River and monthly in the Delaware Inland Bays. Parameters compared were analysed using similar analytical techniques. In the York River, the first station, Guinea Marsh, is located at the mouth of the river in an area where SAV beds consisting of eelgrass and widgeongrass have been abundant and relatively stable over the past 50 years. The second site, Gloucester Point, is located approximately 15 km upriver from Guinea Marsh in an area that marks the current upriver limits of existing vegetation. Transplanting of eelgrass at this site, as part of a major SAV revegetation program funded by the Commonwealth and being conducted in

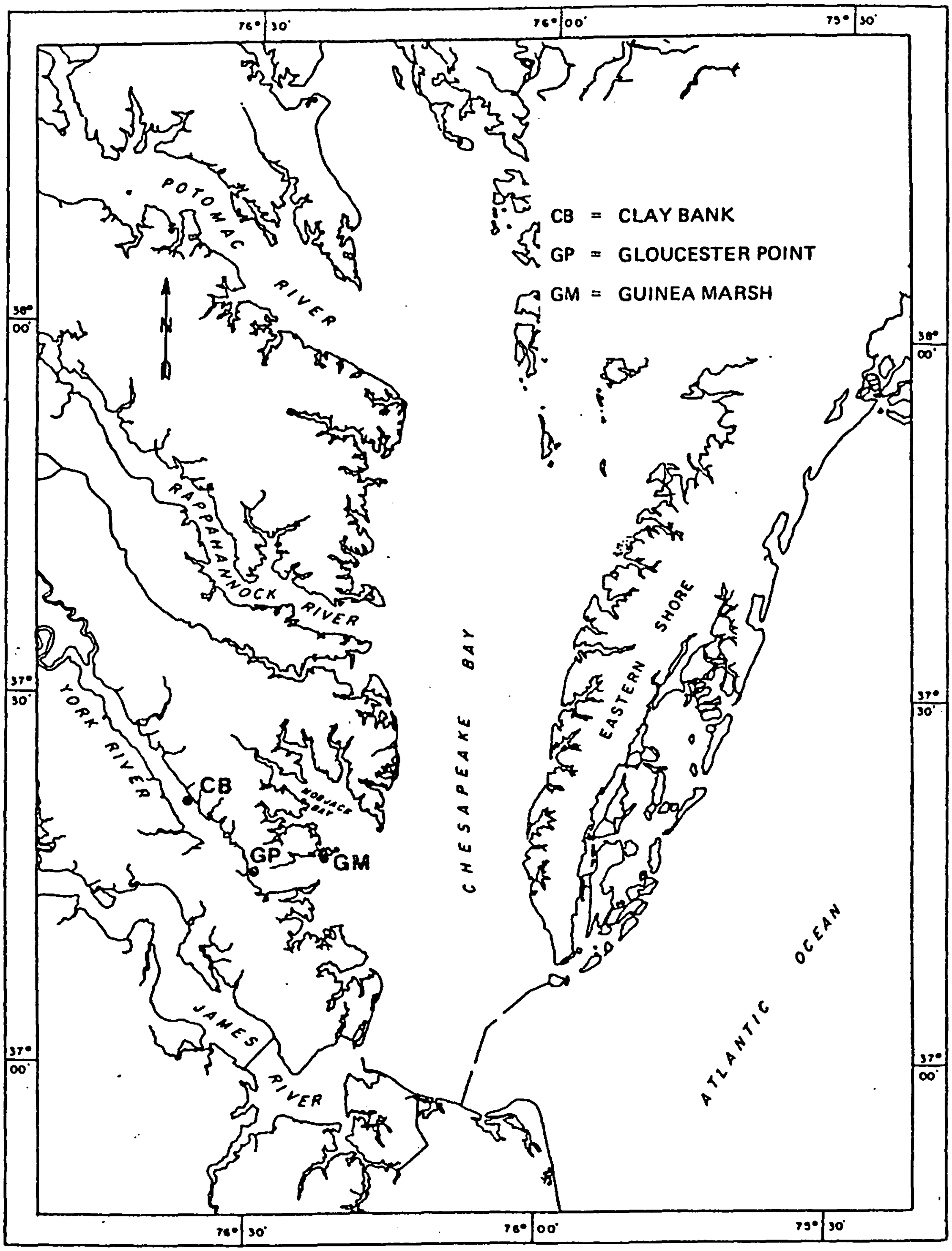


Figure 3. Map of the York River, Virginia, showing the Guinea Marsh, Gloucester Point and Clay Bank locations where environmental data were taken to compare with the Indian River stations. Eelgrass transplanting has been conducted at the Gloucester Point and Clay Bank stations.

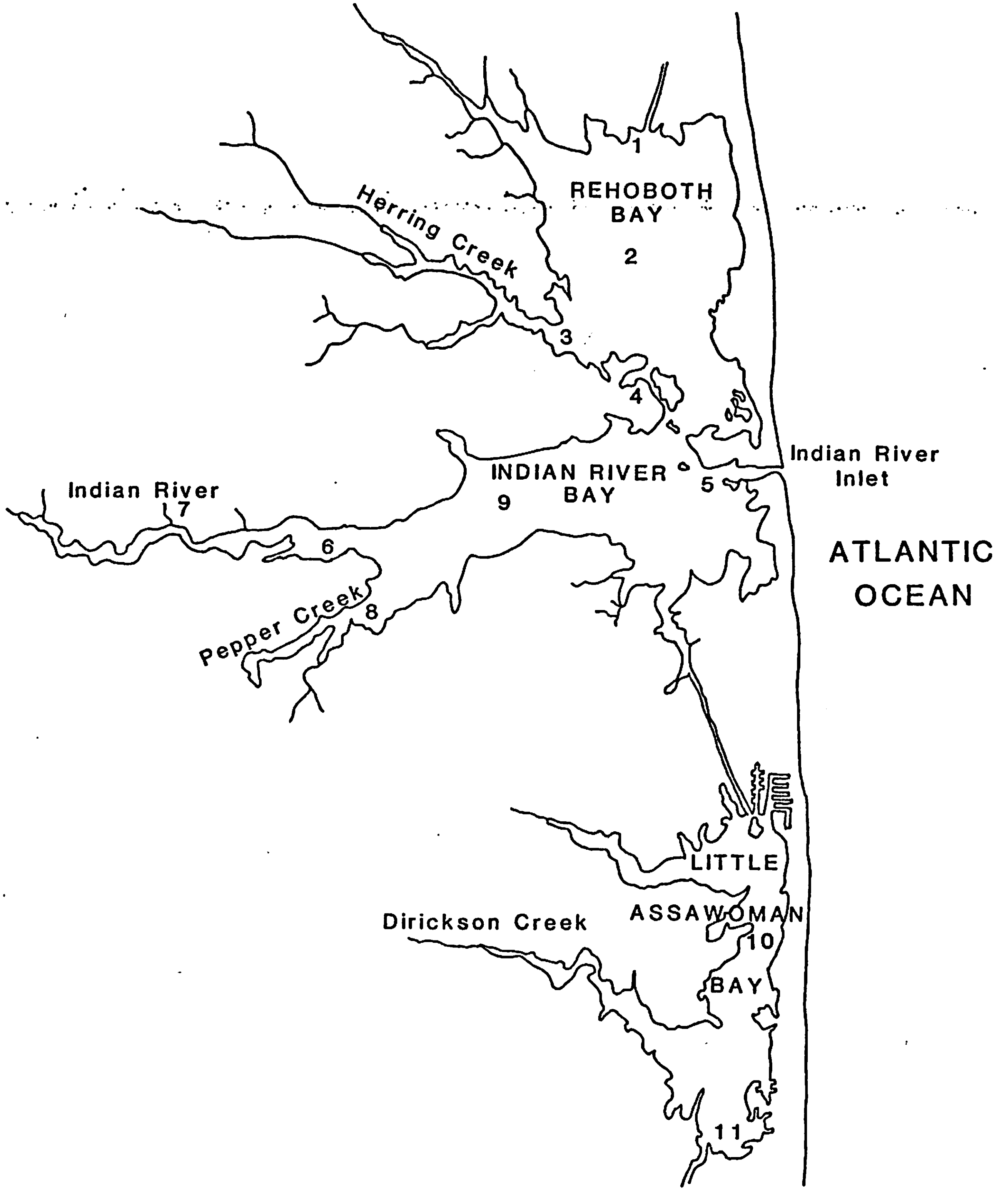


Figure 4. Map of the Indian River and Indian River Bay showing station locations that were used to compare environmental data with the York River stations.

concert with the VIMS environmental monitoring program (Orth and Moore, unpublished data), has been very successful. Both transplanted material and naturally recruited material are surviving and growing very well at this site. The third site, Clay Bank, is located approximately 15 km upriver from Gloucester Point (Fig. 3) in an unvegetated shoal area that formerly (prior to 1973) marked the upstream limits of eelgrass-dominated beds. Transplanting of eelgrass at this site since 1982 has never been successful over a full year. Vegetation planted in the fall does well until late spring but has never survived through the summer. In the Delaware Inland Bays region, water quality parameters in the Rehoboth Bay region were consistent with values obtained along the Indian River and the absence of any historical evidence for SAV in the Rehoboth region permitted us to focus on the Indian River system. Data, as seasonal means, for both the York and the Indian River systems were graphically compared with "Winter" representing December to February, "Spring"-March to May, "Summer"-June to August and "Fall"-September to November.

Comparison of temperature (Fig. 5A and B) and salinity (Fig. 6A and B) illustrate basic similarities in the physical environments of both systems. Thus, there is no reason to conclude that the Indian River system is beyond the salinity or temperature tolerances of eelgrass or widgeongrass. In fact, during this study period for all but the most upstream station, salinities were generally higher at the Indian River stations, a factor that generally favors these marine tolerant species.

Dissolved nutrients do reflect some marked differences in the systems. Dissolved phosphate in the York River (Fig. 7A) demonstrated increasing concentrations upriver during all seasons with mean values in the range of 0.4 to 1.4 ug-at/L (0.01-0.04 mg/L) while the Indian River data (Fig. 7B) displayed varied trends with a distinct spring minimum and an overall range of approximately 0.1 to 1.0 ug-at/L (<0.01-0.03 mg/L). Differences in nitrogen are quite large, however, with levels in the York River (Fig. 8A) being low in comparison to the Indian River stations (Fig. 8B). Only the inlet and lower Indian River Bay stations have inorganic nitrogen ($NH_4 + NO_3 + NO_2$) values comparable to the York River study area. The most upstream Indian River station is very heavily enriched, with over 10 times the ambient levels found in the York River during the winter, spring and summer periods.

Levels of total chlorophyll in the water column demonstrated marked differences between the York and Indian River systems. Mean seasonal levels in the York River (Fig. 9A) are quite low, with levels generally below 10 ug/L, by comparison to the Indian River system (Fig. 9b). Extensive blooms are evident in the Indian River with highest levels observed during the summer. Generally, levels increase with distance upstream and it is only in the immediate vicinity of the Indian River inlet that levels approach those observed in the York River.

Total suspended sediments also demonstrate wide differences between the two systems. In the York River (Fig. 10A), concentrations of suspended matter increase with distance upstream, with highest levels averaging below 20 mg/L. Data from the Indian River system (Fig. 10B) document exceptionally high levels of suspended matter in the water throughout much of the year, with maximum concentrations greater than 130 mg/L. Some of this is due to the high phytoplankton levels, particularly during the summer, while the remainder is likely due to sediments entering from upland drainage as well as the resuspension of bottom sediments already in the system.

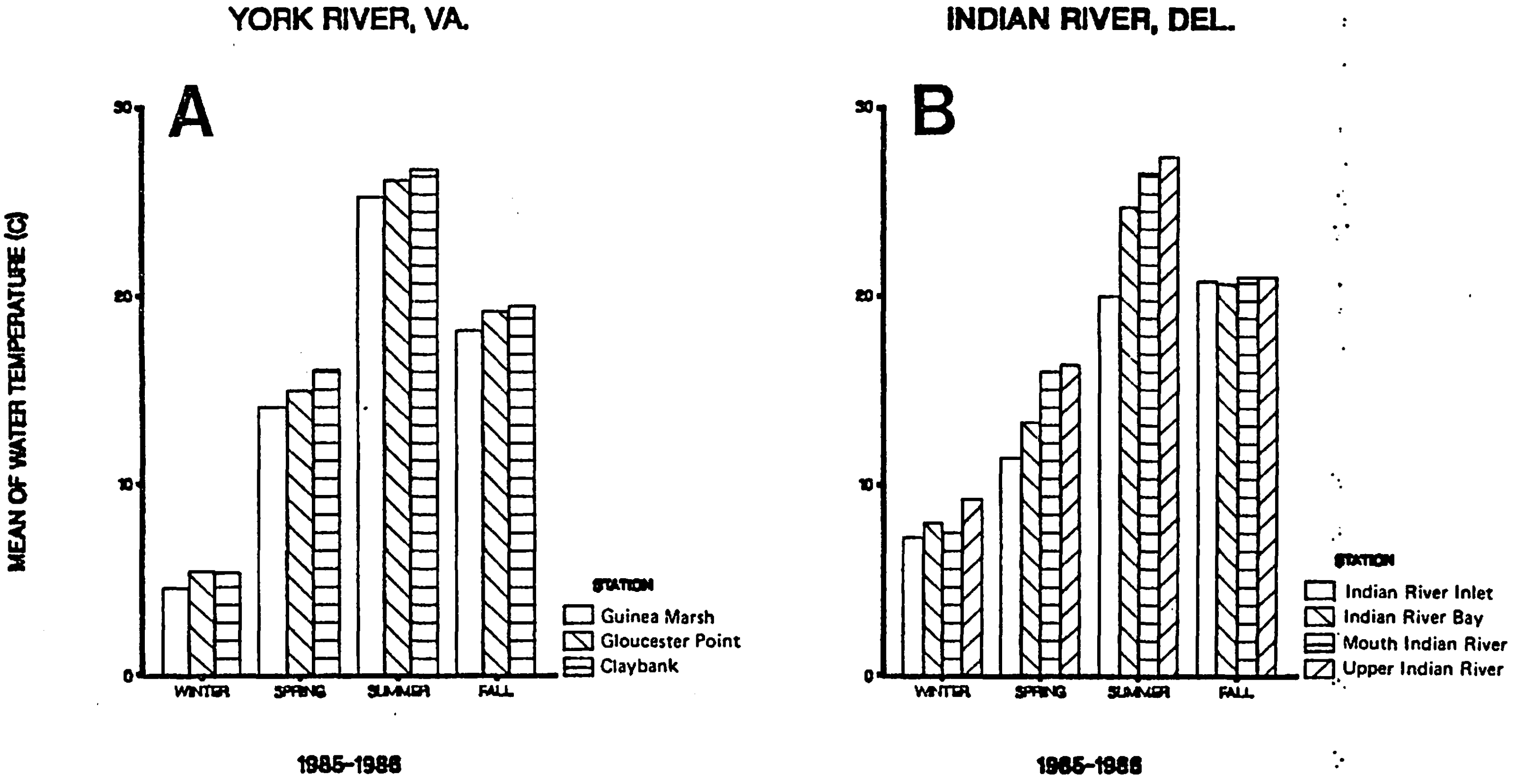


Figure 5. Seasonal means of temperature for stations in (A) York River, Virginia,and (B) Indian River, Delaware.

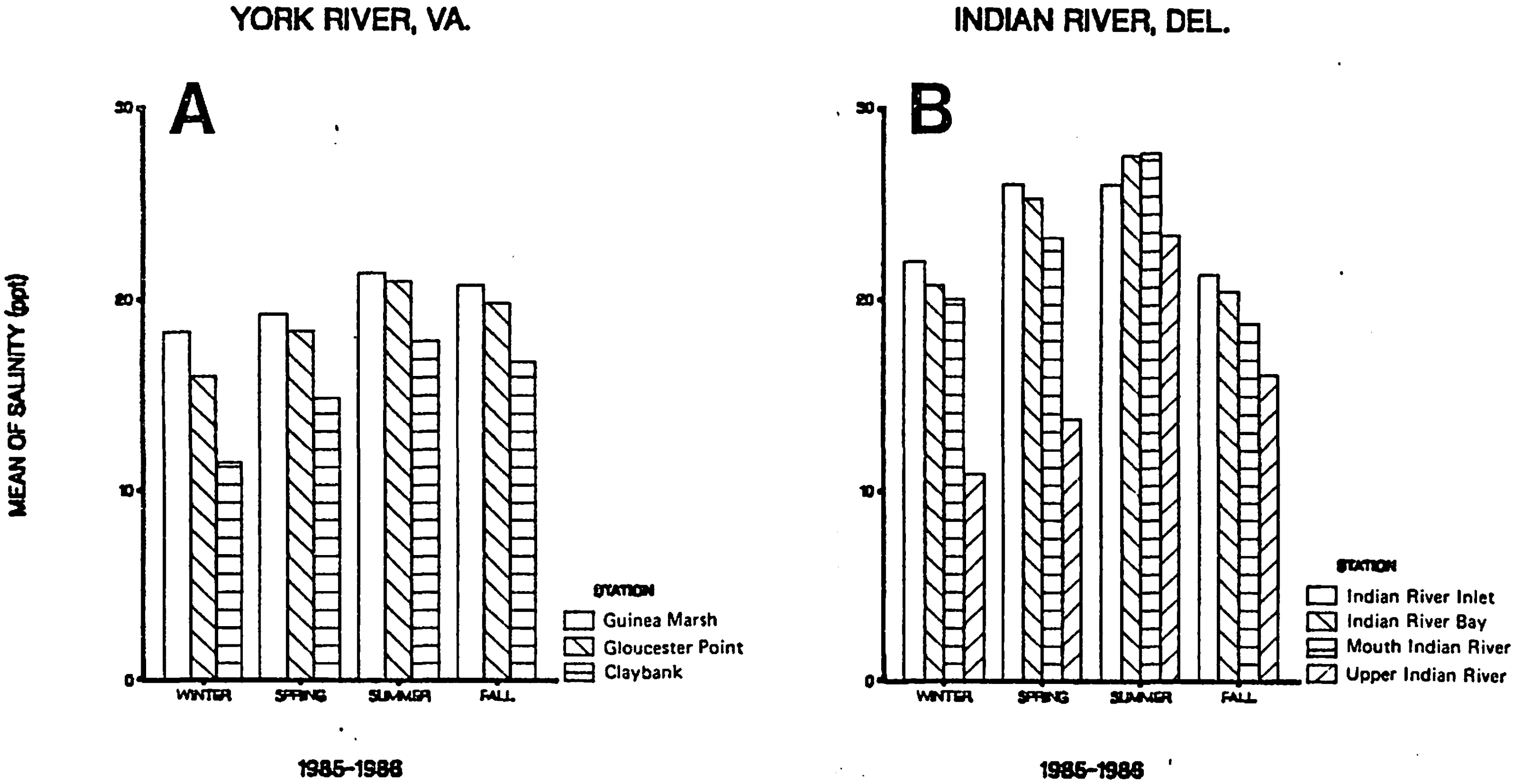


Figure 6. Seasonal means of salinity for stations in (A) York River, Virginia and (B) Indian River, Delaware.

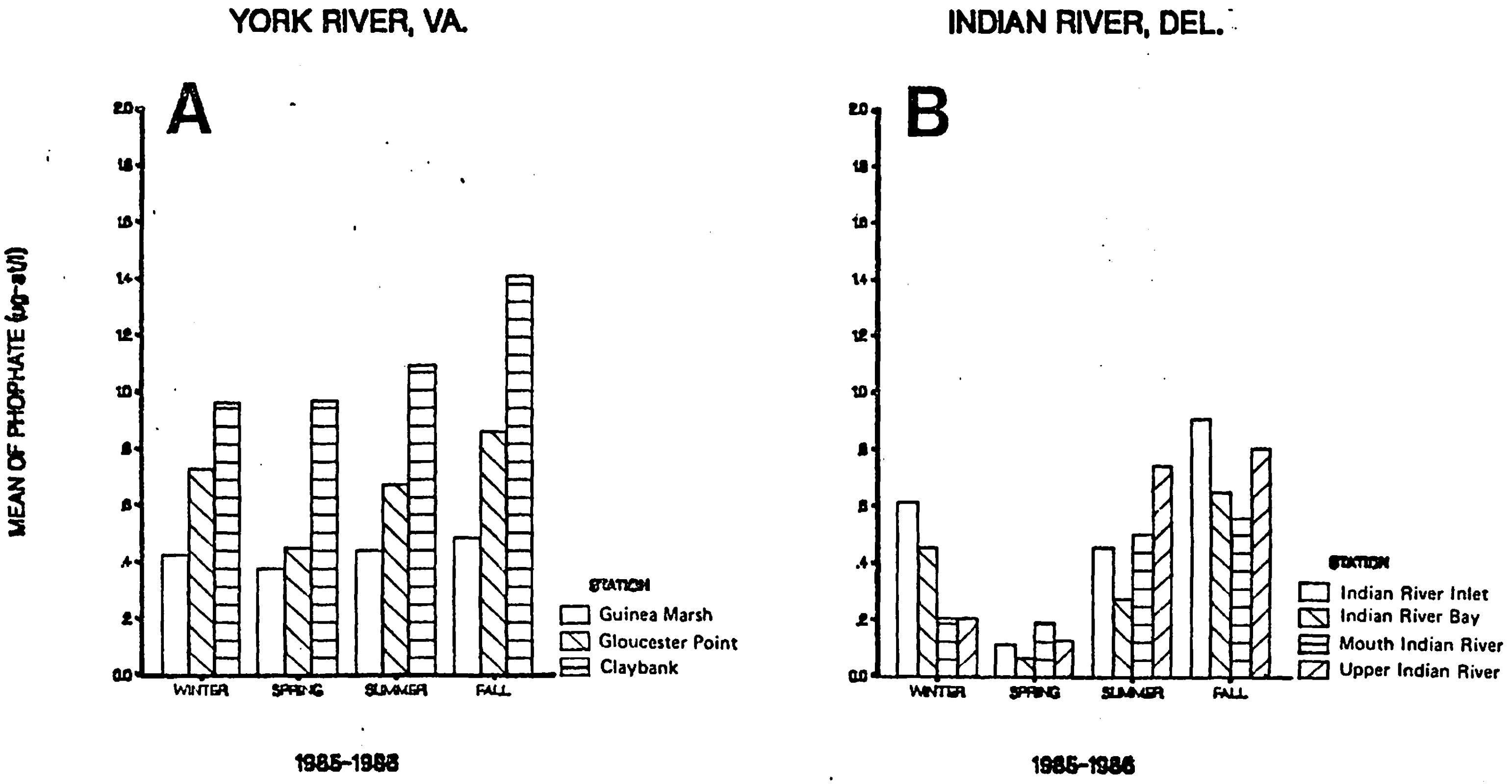


Figure 7. Seasonal means of dissolved inorganic phosphate for stations in (A) York River, Virginia and (B) Indian River, Delaware.

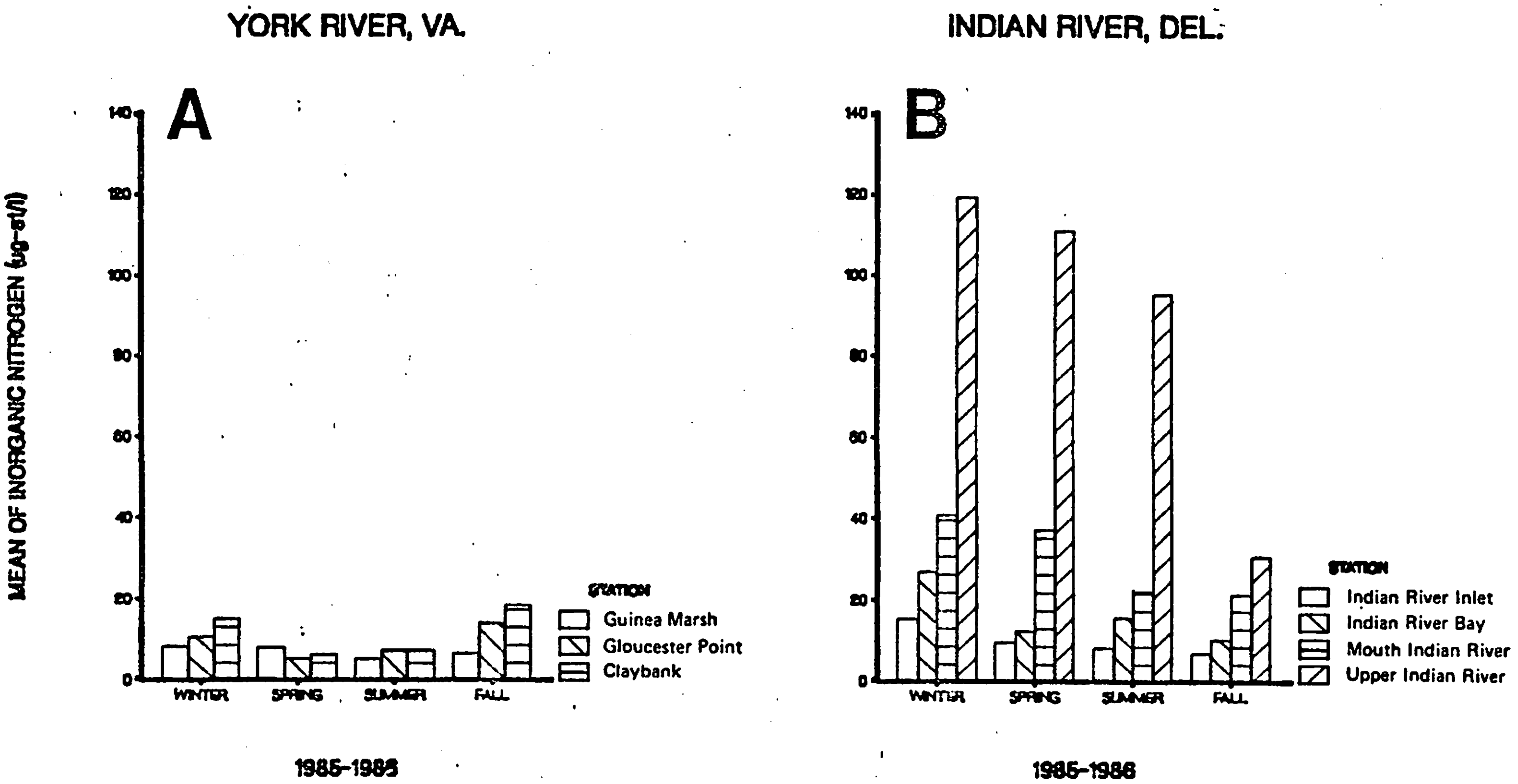


Figure 8. Seasonal means of dissolved inorganic nitrogen for stations in (A) York River, Virginia and (B) Indian River, Delaware.

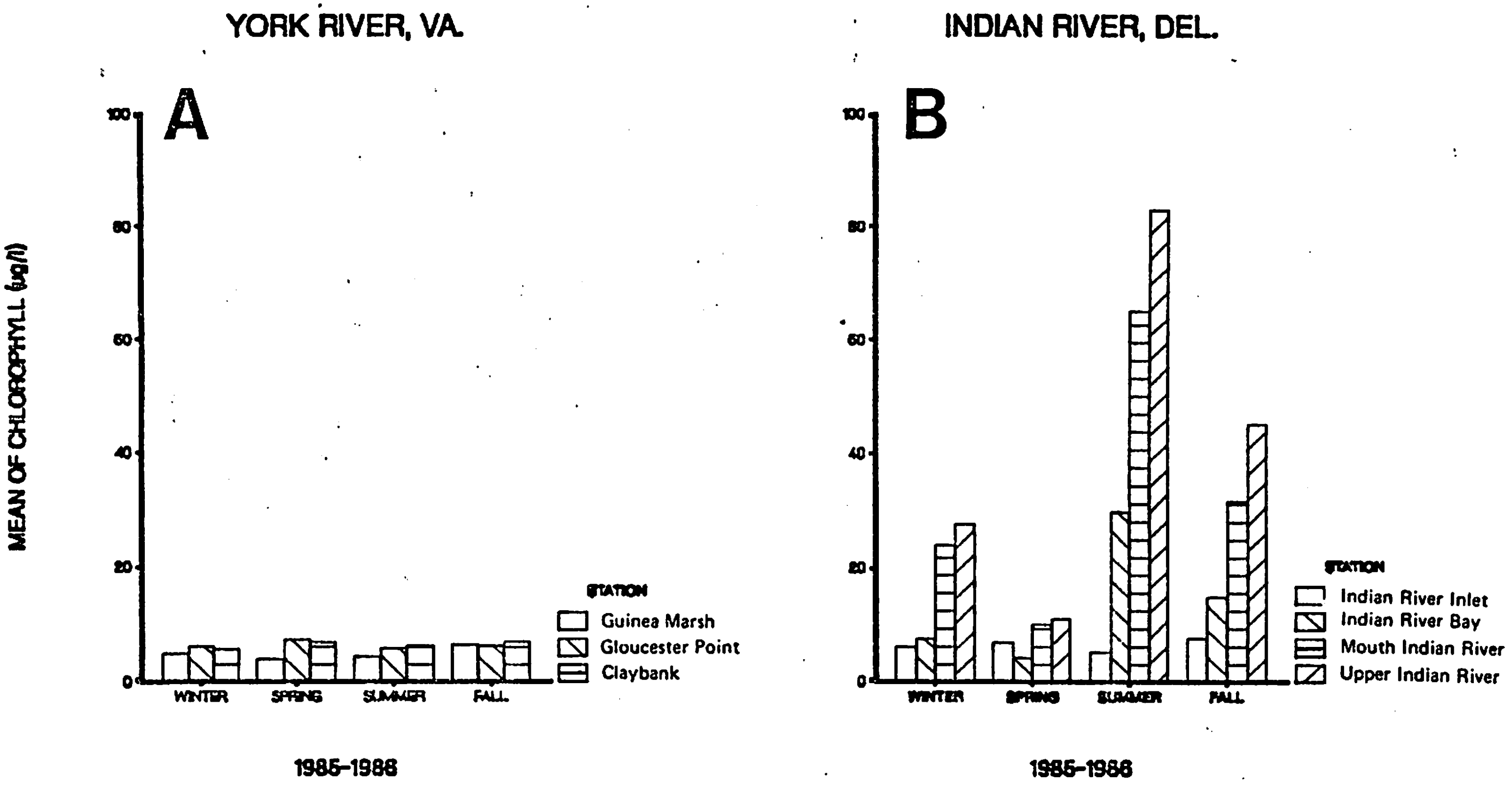


Figure 9. Seasonal means of chlorophyll for stations in (A) York River, Virginia and (B) Indian River, Delaware.

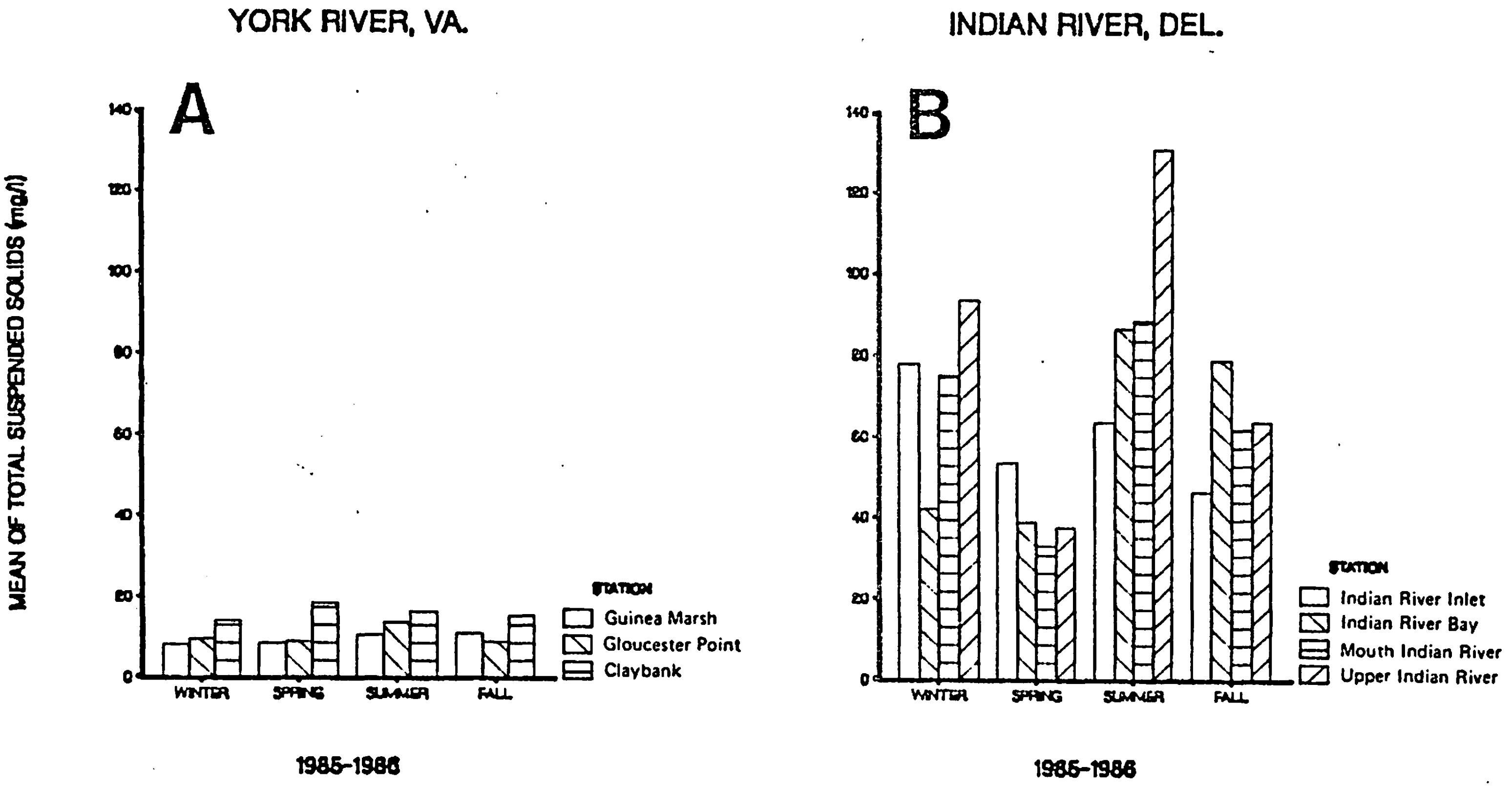


Figure 10. Seasonal means of total suspended solids for stations in (A) York River, Virginia and (B) Indian River, Delaware.

Secchi disk readings obtained during the Delaware Bays study were converted to attenuation coefficient (k) (Idso and Gilbert, 1974) for comparison with the York River data that were obtained by use of an underwater quantum sensor (LICOR 192B, Quantum Sensor). Levels in the York River demonstrated increasing attenuation (decreasing light) with distance upriver during all seasons (Fig. 11A). Highest levels were found at the Clay Bank site in the spring. This is the period of maximum runoff which brings in significant quantities of silts and clays. In the Indian River system (Fig. 11B), the only station which approximated the York River for water clarity was the station located in the inlet. While light attenuation was observed to be low at most stations during the winter, attenuation at all but the inlet station were exceptionally high during the summer and fall.

WATER QUALITY IMPLICATIONS ON POTENTIAL SAV POPULATIONS IN THE INLAND BAYS

Levels of certain water quality parameters in the inland bays, e.g. dissolved nitrogen, chlorophyll, light attenuation, total suspended solids, were much higher than the levels measured in eelgrass beds in the York River. More significantly, levels at all sites in the Indian River and Indian River Bay, except the inlet area, were greater than those recorded at the Clay Bank site in the York River. Clay Bank was the most upriver limit of eelgrass growth prior to the recent major decline documented in the 1970's and transplant experiments have determined that the area is currently unsuitable for eelgrass survival. It is also the site along the gradient of York River stations where levels of nutrients are highest and available light the lowest. Thus, we hypothesize that water quality in this area is poorer than that necessary to support eelgrass growth in the region. Model studies (Wetzel and Neckles, 1986) support this hypothesis. Therefore, considering the water quality observed in the inland bays, it is likely that, in most areas, conditions are limiting for SAV growth. Research to define the precise levels of water quality necessary for eelgrass growth is on-going in Virginia. However, exact limits remain to be determined.

In the York River, eelgrass no longer grows naturally or survives if transplanted in areas such as the Clay Bank site if the attenuation coefficient, or k, is 2.00 or greater. At this level, less than 5% of the incident solar irradiance reaches the bottom in water where the mean depth is 1.5 m. For much of the day, therefore, plants at such a depth would be at or below their compensation depth. This does not include any additional attenuation of light due to epiphytic growth. In the Indian River system, only the inlet stations have k values less than 2.0. In the summer and fall, k values in most area are approximately 4.0, a level at which only 0.2% of incident light would reach the bottom. The attenuation is due to the high levels of total suspended matter in the water column throughout much of the year. This suspended matter includes phytoplankton, inorganic and organic particles. Not only can such high levels have devastating effect on submerged vegetation by attenuating light through the water column but this material can settle and bind to the epiphytes on the leaves, compounding the fouling effects.

The high levels of nutrients, in particular nitrogen, found in the Indian River could pose additional problems for SAV, notably increased epiphyte growth. Twilley et al. (1985) examined plant responses to three levels of nutrient enrichment in experimental ponds in the Chesapeake Bay. They found that biomass of submerged macrophytes decreased significantly under high and medium treatments, compared

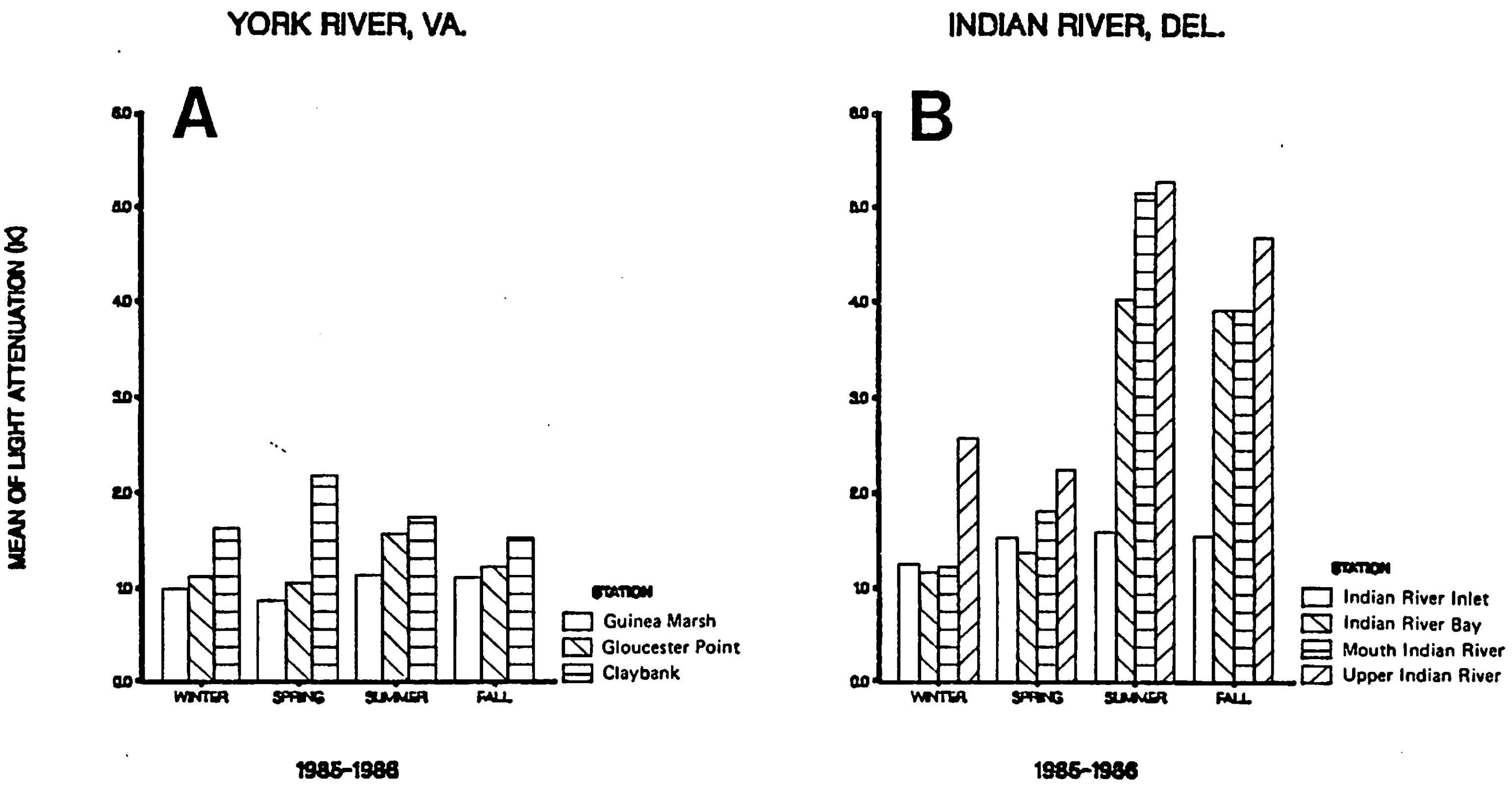


Figure 11. Seasonal means of light attenuation (k) for stations in (A) York River, Virginia and (B) Indian River, Delaware.

to control and low treatments. All fertilized treatments (high, medium and low) had elevated levels of epiphytic material compared to controls, whereas phytoplankton had elevated levels only under the most extreme nutrient addition. Bulthuis and Woelkerling (1983) also found highest rates of biomass accumulation of epiphytes on an Australian seagrass, Heterozostera tasmanica, where nutrient concentrations were highest. They found that growth of epiphyte biomass could occur rapidly enough to shade H. tasmanica leaves and significantly reduce the time (to less than one half of the leaf life span) in which positive net photosynthesis of the leaf blade is possible.

The high levels of suspended chlorophyll, turbidity and dissolved nutrients observed in Delaware's Inland Bays, compared to levels recorded in vegetated areas in the York River, suggest that it is unlikely that SAV species tolerant to the levels of salinity and temperature found here (principally eelgrass and widgeongrass) would be able to survive in the bay system. The only potentially suitable area would be in the immediate vicinity of the inlet where marine influence is greatest.

Transplanting of eelgrass along the east coast has proven successful in North Carolina, Virginia and New York. Presently, Virginia is using transplants as a tool to understand those factors controlling the growth of eelgrass as well as attempting to revegetate denuded areas (Orth and Moore, unpublished data). The mechanics of transplanting have been well established (season for transplanting and planting methods) for the Chesapeake Bay area and should be applicable to the Delaware system. In general, planting is most successful when conducted in the fall months (September to early November) and when bundles of sediment-free shoots are planted in the sediment with a slow release fertilizer. Any proposal to initiate a transplant project should consider the site and depth of water at the site. Criteria should, at a minimum, include the fact that SAV must have previously grown at the site. Any plantings should be frequently monitored as should environmental parameters in the water column. Transplanting in conjunction with a detailed monitoring program at the site could identify factors that would affect the growth of the plants. This could provide managers with needed information as to the important parameters necessary to improve water quality so that SAV populations could recover.

We recommend that Delaware initiate a small scale eelgrass transplant project to determine if the Delaware Inland Bay system can support eelgrass. This project should be conducted as close to the Inlet as possible where eelgrass used to grow and where present environmental conditions, except for possibly suspended solids, appear most suitable, based on a comparison with our data from the Chesapeake Bay. Plantings should occur in the fall (September being optimum) using whole plants obtained from the Chincoteague Bay area. Eelgrass is currently thriving in Chincoteague Bay, principally in areas along the east side behind Assateague Island (Orth et al., 1987). Plants should be fertilized with a small amount of slow-release fertilizer (Osmocate) placed in the sediment adjacent to the roots. Plants should be monitored monthly except for semi-monthly from May to August, the period when we have observed the most rapid changes in Chesapeake Bay transplant efforts. Water quality parameters, especially light intensity, should also be monitored regularly in the area where the plants are located. We expect that results from these efforts should provide data on the potential for SAV growth in the region.

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