# Chesapeake Bay: An Unprecedented Decline in Submerged Aquatic Vegetation

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# Chesapeake Bay: An Unprecedented Decline in Submerged Aquatic Vegetation

Abstract. *Data on the distribution and abundance of submerged aquatic vegetation in Chesapeake Bay indicate a significant reduction in all species in all sections of the bay during the last 15 to 20 years. This decline is unprecedented in the bay's recent history. The reduction in one major species,* Zostera marina, *may be greater than the decline that occurred during the pandemic demise of the 1930's.*

Chesapeake Bay (*1*), with its extensive littoral zone and broad salinity range (0 to 33 per mil), supports many different species of submerged aquatic vegetation (*2*). Our synthesis of relevant studies on submerged grasses in the bay and its tributaries (*3*) indicates that the present distribution and abundance of these grasses are at their lowest levels in the bay's recorded history (Fig. 1). The decline, which began in the 1960's and accelerated in the 1970's, has affected all species in all areas. Many major river systems are now totally devoid of any rooted vegetation.

Data used to determine the present and past distribution of bay grasses were acquired from recent aerial mapping studies (*4*), field surveys by state and federal laboratories (*5*), biostratigraphical analyses of estuarine sediments for seeds and pollen of bay grasses (*6*), older archived photographs (*7*), and anecdotal information (*8*). The abundance trends of submerged vegetation at six lower bay sites (Virginia portion) from 1937 to 1980 are shown in Fig. 2a. These sites are dominated by *Zostera marina* and *Ruppia maritima*. From 1937 through the 1960's, the abundance of vegetation increased at five of the sites and then declined precipitously in the early 1970's. By 1980, two of the sites were devoid of vegetation.

Trends of vegetation occurrence in the upper bay (Maryland section) between 1971 and 1980 are shown in Fig. 2b. In 1971, 29 percent of 644 stations sampled within 26 different areas were vegetated, whereas only 10 percent of these stations were vegetated in 1980. Of these 26 areas, 81 percent had vegetation in 1971 as compared to only 38 percent in 1980. At eight of the 26 areas, vegetation declined rapidly between 1971 and 1973 and by 1980 was absent at four of the formerly vegetated sites (Fig. 2c).

The pattern of vegetation loss has not been uniform throughout the bay. Areas densely vegetated in the Patuxent and lower Potomac rivers (*9*) in the 1960's were devoid of vegetation by 1970. Upriver sections of many smaller subestuaries were devoid of vegetation by 1970. Major changes in all regions began in 1972, the year of Tropical Storm Agnes. This storm reduced salinities throughout the bay for periods of up to 4 weeks and transported large quantities of suspended sediment into the estuarine system (*10*). By 1974, the distribution and abundance of submerged grasses had been drastically altered throughout the bay. This alteration continued, and by 1980 the major tributaries of the bay and many of the smaller rivers contained only sparse beds or completely lacked vegetation. This condition has persisted through 1982, although beds have been expanding to a modest degree in the lower York River during the last 3 years (*11*). In some areas where declines of vegetation occurred gradually rather than abruptly reductions occurred first in the outer deepwater fringes of the beds. One site in the lower bay showed a progressive shoreward shift of the bed's outer limits over a 10-year period (*3*).

We believe that the observed vegetation decline is unprecedented in the bay's recorded history for several reasons. (i) Detailed biostratigraphical analysis of sediments for submerged aquatic vegetation seeds and pollen from at least one site indicates the continued presence

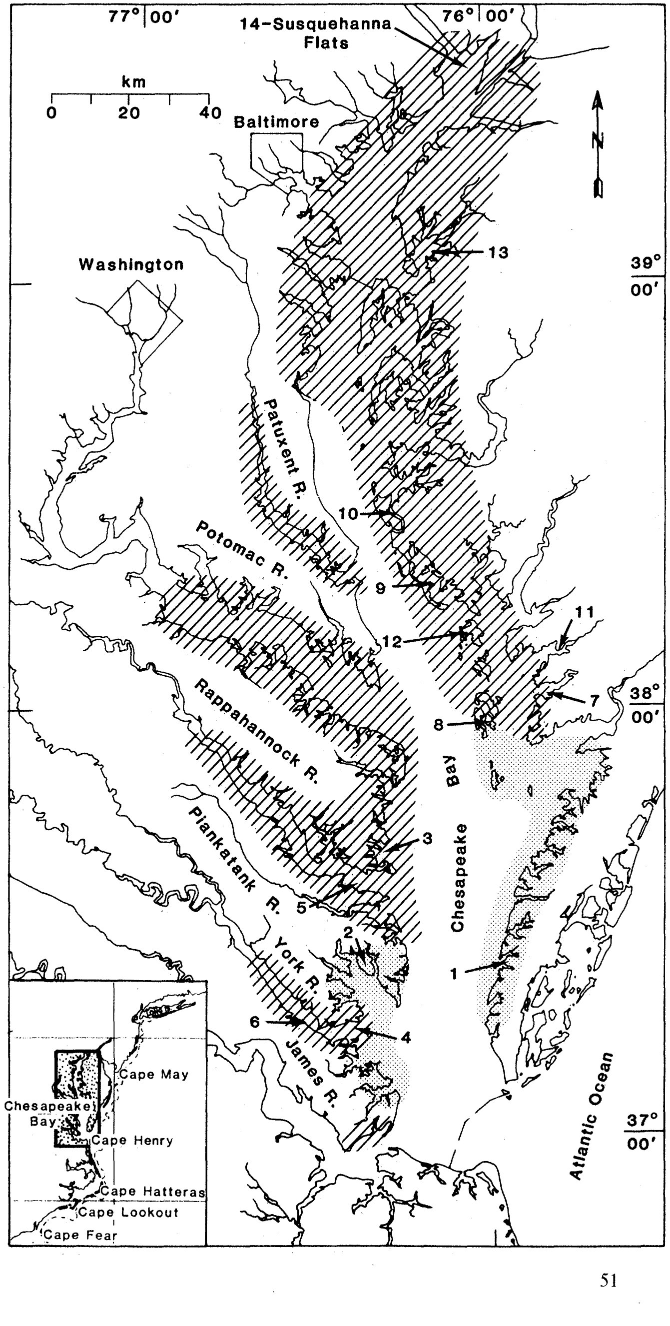

Fig. 1. Map of the Chesapeake Bay showing areas where submerged aquatic vegetation has experienced the greatest decline since 1960 (diagonal lines) and locations where vegetation is still found in large stands (stippled areas). Numbers indicate locations referred to in Fig. 2.

of such seeds from the 18th century to 1972 when they abruptly disappeared from the record (*6*). (ii) Photographic and anecdotal evidence indicates that extensive areas were vegetated with *Z. marina* in 1937, 4 to 5 years after the pandemic decline of the 1930's (*12*). In contrast, today, nearly 10 years after the more recent dieback, many of these same areas remain unvegetated. (iii) The current decline has affected all species throughout the bay rather than one species or one localized area.

This decline of vegetation appears to be restricted to Chesapeake Bay. We know of no reported large-scale declines of *Z. marina* or other aquatic estuarine grasses from the East Coast. In some areas, such as Long Island Sound, *Z. marina* is increasing in abundance (*13*).

The causes that have led to the Chesapeake Bay decline may be related to factors affecting the quantity and quality of light reaching the plant surface (*14*). There are similarities between the areas of greatest reduction in aquatic grass species and areas of greatest nutrient enrichment (*15*). Nutrients not only stimulate phytoplankton growth but also periphyton growth on the leaf surface, both of which reduce the light available to the plant. Biological factors such as the reduction of the periphyton grazing community from *Z. marina* beds in the lower bay may also be a significant factor (*16*).

Secondary impacts from the loss of vegetation have been documented or observed. Several waterfowl species that utilize this resource have declined (*17*), while some shoreline areas, once protected by the baffling effects of the plants, may be experiencing increased erosion. Implications for commercially important species, for example, the blue crab, *Callinectes sapidus*, which use the grass areas for shedding and as a nursery, have not been determined (*18*) but could be considerable.

The evidence of a major, regionally isolated change in the submerged grass communities of Chesapeake Bay over the last 20 years suggests that this estuarine system has been undergoing an environmental stress of major proportions. Although storms may have hastened the decline in certain sections of the bay, the overall pattern appears to be one of chronic decline that began in the upriver and upper bay areas and continues to the present. Although we have noted initial signs of vegetational recovery in areas containing sparse patches of grass, the recovery in areas that are totally devoid of vegetation and far removed from a source of potential propagules is minimal. If the present decline is related to changes in water quality, submerged vegetation may not recover unless these conditions are rectified.

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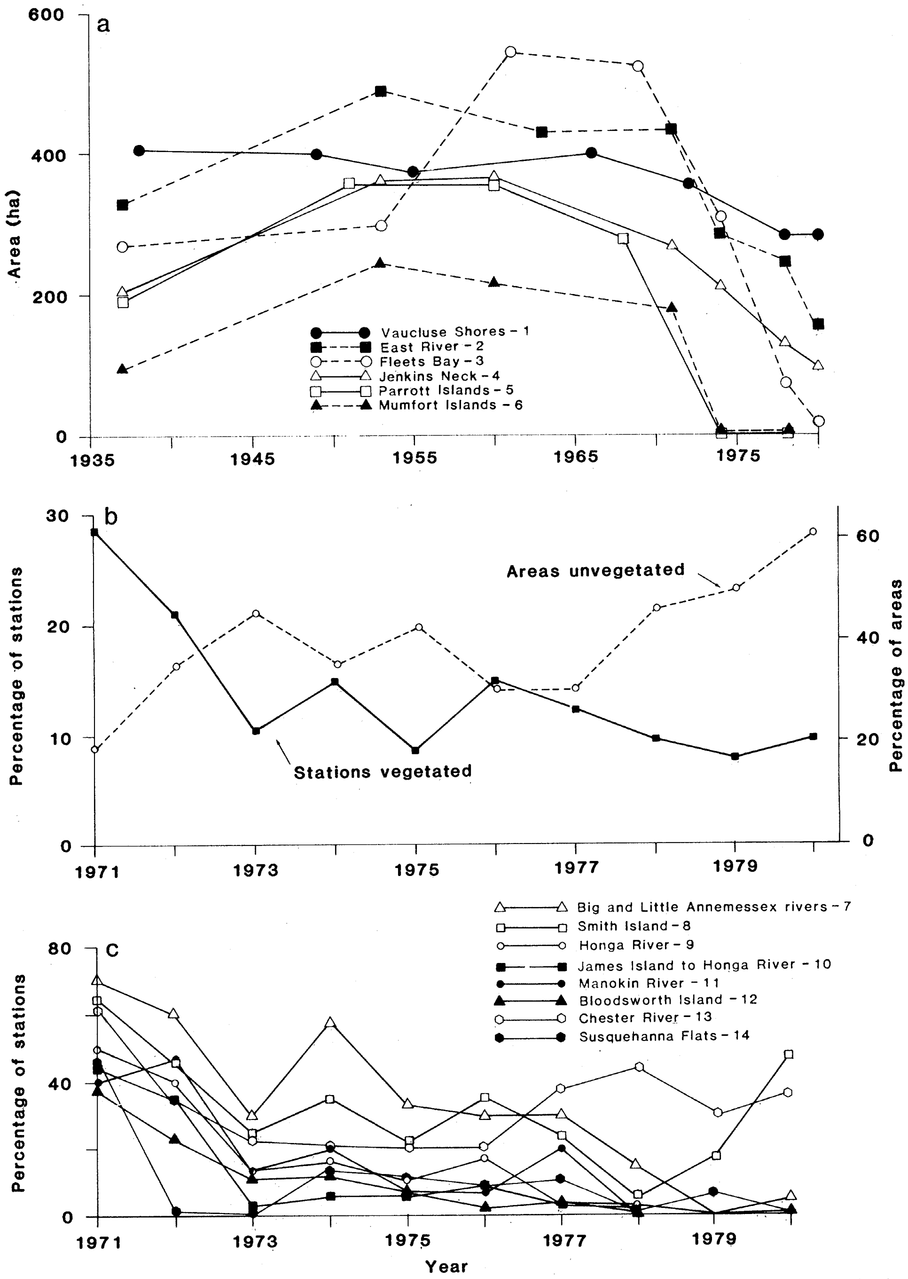

Fig. 2. (a) Trends in the areal coverage of submerged aquatic vegetation at six intensively mapped areas in the lower Chesapeake Bay, 1937 to 1980. The precision of the data is approximately 2 percent [data derived from aerial photographs (*4*)]. (b) Trends in the occurrence of submerged aquatic vegetation in the Maryland portion of Chesapeake Bay. Values represent the percentage of stations with vegetation ($N$ = 644) and the percentage of unvegetated areas ($N$ = 26) from 1971 to 1980. Survey data were designed to detect a 5 percent change in the overall study area [data from the U.S. Fish and Wildlife Service and the Maryland Department of Natural Resources Surveys (*5*)]. (c) Trends in the occurrence of submerged vegetation at eight of the 26 areas noted in (b).

## References and Notes

1. Chesapeake Bay is the largest and one of the most productive estuaries in the world. It is 290 km long and has 13,000 km of shoreline with a drainage basin of 167,760 km$^2$. The bay system is a valuable national resource in terms of fisheries production, wildlife habitat, shipping and commerce, and recreation. However, conflict among its uses is escalating as the surrounding population increases to a projected 12.5 × 10$^6$ by 2000 [L. E. Cronin, in *Transactions of the 46th North American Wildlife and Natural Resources Conference* (Wildlife Management Institute, Washington, D.C., 1981), p. 223].
2. Ten species of submerged vegetation are abundant in the bay. *Zostera marina* and *Ruppia maritima* are dominant in the lower reaches. *Myriophyllum spicatum, Potamogeton pectinatus, P. perfoliatus, Zannichellia palustris, Vallisneria americana, Elodea canadensis, Ceratophyllum demersum,* and *Najas guadilupensis* are less tolerant of high salinities and are found primarily in the middle and upper reaches [R. R. Anderson, *Chesapeake Sci.* **13**, S87 (1972); J. C.

Stevenson and N. M. Confer, *Summary of Available Information on Chesapeake Bay Submerged Vegetation* (Publication FWS/OBS-78/66, Fish and Wildlife Service, Office of Biological Services, Washington, D.C., 1978)].

3. R. J. Orth and K. A. Moore, in *Chesapeake Bay Program Technical Studies: A Synthesis* (Final Report, Environmental Protection Agency, Washington, D.C., 1982), p. 381.
4. R. J. Orth and H. H. Gordon, Final Report, National Aeronautics and Space Administration contract NAS1-10720 (1975); R. J. Orth, K. A. Moore, H. H. Gordon, Final Report, Environmental Protection Agency 600/8-79-029/SAV1 (1979); R. J. Orth, K. A. Moore, J. van Montfrans, Final Report, Environmental Protection Agency grant X003246 (1982); R. R. Anderson and R. T. Macomber, Final Report, Environmental Protection Agency grant R805970 (1980).
5. Information was available from either data reports by the Maryland Department of Natural Resources and the Patuxent Wildlife Research Center of the U.S. Fish and Wildlife Service or data reported by Stevenson and Confer [see (*2*)]. Important published works included the following: S. Bayley, V. D. Stotts, P. F. Springer, J. Steenis, *Estuaries* **1**, 171 (1978); J. A. Kerwin, R. E. Munro, W. W. A. Peterson, in *The Effects of Tropical Storm Agnes on the Chesapeake Bay Estuarine System*, J. Davis and B. Laird, Eds. (Johns Hopkins Univ. Press, Baltimore, 1977), p. 393.
6. G. S. Brush, F. W. Davis, S. Rumer, Final Report, Environmental Protection Agency grant R205962 (1980); G. S. Brush, F. W. Davis, C. A. Stenger, Final Report, Environmental Protection Agency grant R806680 (1981).
7. Photographs were available from the U.S. Geological Survey, the U.S. Department of Agriculture Soil Conservation Service, the National Oceanic and Atmospheric Administration, the Virginia Department of Highways, and the National Aeronautics and Space Administration. The earliest photographs were taken in 1937 by the Soil Conservation Service.
8. We surveyed numerous watermen, hunters, fishermen, and owners of homes on the bay's shoreline who were familiar with the submerged vegetation. Many of their remarks confirmed trends noted in more quantitative surveys.
9. Vegetation in this part of the Potomac was *Z. marina*. Intensive surveys by the U.S. Geological Survey revealed localized but small stands of vegetation in portions of the river up to Washington, D.C., in the late 1970's [G. M. Haramis and V. Carter, *Aquat. Bot.* **15**, 65 (1983)].
10. J. Davis and B. Laird, in *The Effects of Tropical Storm Agnes on the Chesapeake Bay Estuarine System*, J. Davis and B. Laird, Eds. (Johns Hopkins Univ. Press, Baltimore, 1977), pp. 1–29.
11. We have monitored the north shore of the lower York River since 1974 for changes in both existing beds of *Z. marina* and denuded areas. This species has increased in abundance in several sections, apparently from germination and growth of seeds transported from adjacent beds. Transplantation of *Z. marina* into denuded areas has been attempted with the greatest long-term success in areas closest to existing vegetation [R. J. Orth and K. A. Moore, Final Report, Environmental Protection Agency grant R805953 (1982)].
12. A. D. Cotton, *Nature (London)* **132**, 277 (1983); R. W. Butcher, *ibid.* **135**, 545 (1935); C. Cottam, *ibid.*, p. 306; C. E. Renn, *ibid.*, p. 544; E. Rasmussen, *Ophelia* **11**, 1 (1973).
13. We contacted scientists and resource managers in states from North Carolina to Maine. There were no reports of declines of submerged vegetation. A. C. Churchill (personal communication) reported increases in Long Island Sound during the period when the bay was experiencing the decline.
14. "Submerged aquatic vegetation" (synthesis paper summary), in *Chesapeake Bay Program Technical Studies: A Synthesis* (Final Report, Environmental Protection Agency, Washington, D.C., 1982), pp. 633–635. Herbicides were initially implicated in the decline, but final results indicated that they were not the single cause.
15. Examination of long-term data bases (up to 30 years) showed increases in phosphorus, nitrogen, and chlorophyll *a* in many regions of the bay [D. R. Heinle *et al.*, Final Report, Environmental Protection Agency grant R806189 (1980)].
16. J. van Montfrans, R. J. Orth, S. Vay, *Aquat. Bot.* **14**, 75 (1982).
17. M. C. Perry *et al.*, in *Transactions of the 46th North American Wildlife and Natural Resources Conference* (Wildlife Management Institute, Washington, D.C., 1981), p. 299.
18. The commercial catch of hard blue crabs in the bay during the 1970's was below average. Speculation has centered on the decline of vegetation as a possible cause. Commercial crabbers have had problems harvesting peeler crabs in areas where vegetation was once abundant (W. Conley and R. C. V. Seafood, personal communication).
19. Our work was supported by grants R805951, X003201, and X003246 from the Environmental Protection Agency Chesapeake Bay Program to the Virginia Institute of Marine Science. We thank A. Evans, J. van Montfrans, and K. Webb for critical reviews of this manuscript. This is contribution No. 1124 from the Virginia Institute of Marine Science.

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# Free Cupric Ion Activity in Seawater: Effects on Metallothionein and Growth in Crab Larvae

Abstract. *Crab zoeae (*Rhithropanopeus harrisii*) were exposed during their development to a range of free cupric ion activities regulated in seawater by use of a copper chelate buffer system. Most cytosolic copper was found to be associated with metallothionein. Copper-thionein could be related to free cupric ion activity, and a shift in copper-thionein accumulation was correlated with inhibition of larval growth. These data reveal predictable relations between cupric ion activity in seawater and processes at the cellular and organismic levels.*

The biological impact of increases in trace metal concentrations in the oceans has become a major concern (*1*). Trace metals such as copper at nanomolar concentrations similar to those in natural seawater inhibit nutrient uptake in both phytoplankton (*2*) and bacteria (*3*). However, numerous chemical species of copper are present in natural seawater (*4*), and chemical speciation often varies considerably between samples (*3*). The biological availability and toxicity of copper appear to be related to free cupric ion activity, $\{Cu^{2+}\}$, rather than to total copper concentration or the concentration of copper complexes (*3, 5*). Since most copper toxicity studies have related cellular or organismic responses to total copper added to seawater (*6*), the biological availability of the metal, even on a relative scale, is usually unknown.

The cysteine-rich metal-binding protein metallothionein serves as a major intracellular metal-binding ligand whose synthesis can be induced by metals, including copper, cadmium, zinc, and mercury (*7*). Metallothioneins are widely distributed and have been isolated from various vertebrates, invertebrates, and higher plants (*8, 9*). These proteins have been associated with metal uptake, metabolism, and detoxification (*7*). The primary structure of crab thionein is homologous to both mammalian and fungal thioneins, and its synthesis is induced by copper, zinc, and cadmium (*9, 10*).

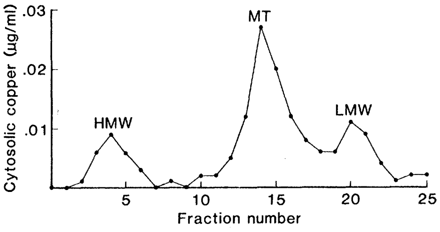

Fig. 1. Cytosolic distribution of copper in crab larvae (*R. harrisii*) exposed to free cupric ions in seawater (*13*). *HMW*, *MT*, and *LMW* represent high molecular weight, metallothionein, and low molecular weight pools, respectively.

Research on the mechanisms of copper toxicity has focused on either biochemical responses (for example, metallothionein synthesis) or physiological effects at the population level (for example, growth rate), but not at both biological levels simultaneously (*6*). As a consequence, the relations between metal exposures, metallothionein synthesis, and population effect remain unclear. Correlating the amount of biologically available copper in seawater with cellular and molecular data and with the impact on organisms and populations is even more difficult. However, predictions of the ecological consequences of increased copper in seawater and of subsequent copper accumulation and subcellular distribution will be possible only if they can be related to population effects. In this study we have used a copper–nitrotriacetic acid (NTA) buffer system (*11*) to control free cupric ion activity, and have examined the relations between $\{Cu^{2+}\}$ in seawater, cytosolic copper, copper-thionein accumulation, and growth in crab larvae. Our data indicate that copper-thionein can be related to $\{Cu^{2+}\}$ in seawater and that a shift in copper-thionein accumulation is correlated with inhibition of larval growth.

Newly hatched larvae of the mud crab *Rhithropanopeus harrisii* were exposed to a range of $\{Cu^{2+}\}$ values for the duration of zoeal development (*12*). The larvae were sampled immediately after they had molted to the megalopa stage. Survival, time to megalopa, and dry weights