Water Quality Standards Based on Species' Habitat Requirements

A Case Study from the Chesapeake Bay Using Submerged Aguatic Vegetation

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Introduction

A diverse array of biologically productive habitats are found in all coastal areas of the United States, ranging from upland, deciduous forests and non-tidal, freshwater wetlands to both vegetated and nonvegetated rivers, lagoons, and estuaries. Each habitat supports large numbers of permanent and transient plant and animal species.

The growth, distribution, abundance, and survival of any one species is regulated by a set of requirements unique to it that include dissolved oxygen, light, and nutrients. Each species survives within a range of values for any particular parameter below which it experiences stress and may eventually die. However, species survival depends on the integration of responses to all parameters that are important for its growth. Tolerances to one parameter (such as dissolved oxygen) may either be increased or decreased by interaction with one or more additional parameters (temperature, salinity).

A complete understanding of the species' habitat requirements is critical to understanding its response to environmental perturbations, in particular those that may affect water quality for estuarine and coastal environments. Although there are Federal and State water quality standards for rivers and estuaries, in many cases they have been generated for "fishable, swimmable, and drinkable"

purposes. In general, they do not consider the unique characteristics and requirements of the multitude of species that make up a natural ecosystem.

Many of our estuaries are experiencing serious water quality problems primarily because of the pressures from the ever-increasing numbers of people moving near these areas. Most noticeable of all changes are declines in many harvestable living resources, such as fish and shellfish. Of equal concern are losses of other critical elements of the food chain that often go undetected because of inadequate funds for monitoring.

The observed declines have stimulated a major question about water quality: are declines occurring as a result of inadequate enforcement of existing standards, or *are existing standards inadequate to* protect the living resources? If the latter is the answer, what procedures and parameters should we adopt to adequately protect living resources?

The Chesapeake Bay Agreement

Chesapeake Bay, the Nation's largest estuary, has received considerable attention over the last two decades from scientists, managers, politicians, and the public. Declines in water quality related to increasing nutrient enrichment, high levels of contaminants, anoxic or hypoxic conditions, and changes in abundances of living resources are some of major issues facing the bay. Increasingly, scientists and managers are recognizing that, to reach the goal of a clean, healthy waterbody, we must reexamine water quality standards—specifically those new standards relating to the habitat requirements of the species living in the Chesapeake Bay.

In 1987, a historic Chesapeake Bay Agreement was signed that set as a major priority the "need to determine the essential elements of habitat quality and environmental quality necessary to support living resources and to see that these conditions are attained and maintained." The Chesapeake Bay Program's Implementation Committee called for guidelines to determine habitat requirements for the bay's living resources. A document, "Habitat Requirements for Chesapeake Bay Living Resources," first drafted and adopted in 1987 (Chesapeake Bay Progr. 1988), has been undergoing revisions to provide more detailed requirements for living resource habitat. Because submerged aquatic vegetation (SAV) is a critical part of the bay's food chain and is sensitive to water quality (Orth and Moore, 1988), it is a potential indicator of the bay's health and therefore was included in these documents.

Over the last 23 years, Chesapeake Bay's SAV has received considerable scientific attention because of an unprecedented, baywide decline of all species (Orth and Moore, 1983). This decline has been related to the increasing amounts of nutrients and sediments entering the bay as a result of the continuing, uncontrolled development of its shoreline and watershed and poor land use practices associated with this development (Kemp et al. 1983).

Both the Chesapeake Bay SAV Management Policy and Chesapeake Bay SAV Policy Implementation Plan (Chesapeake Exec. Counc. 1989, 1990) highlighted not only the need to develop SAV habitat requirements but also baywide SAV restoration goals for habitat quality, species abundance, and species diversity. In response to the commitments described in the Implementation Plan, a working group of scientists and managers produced the Chesapeake Bay SAV Habitat Requirements and Restoration Goals Technical Synthesis (Batiuk et al. in review).

SAV Technical Synthesis

The SAV technical synthesis program had three major goals:

- To develop quantitative levels of relevant water quality parameters necessary to support continued survival and propagation of SAV;
- To establish regional distribution and diversity goals for the Chesapeake Bay; and
- To document baywide applicability of habitat requirements developed through case studies used in the synthesis.

The development of SAV habitat requirements was described in four case studies spanning all the bay's salinity regimes: tidal fresh water, Potomac River; oligohaline (0.5-5 ppt), Susquehanna Flats; mesohaline (5-18 ppt), Choptank River; and polyhaline (18-25 ppt), York River (Fig. 1). Interpretation of transplant and monitoring data from the upper Chesapeake Bay and a decade of data spanning the revegetation of the upper tidal Potomac River yielded habitat requirements for tidal fresh and oligohaline SAV species. A variety of transplant, research, and monitoring studies in the Choptank and York rivers provided data to develop habitat requirements for mesohaline and polyhaline SAV species, respectively.

Through multi-investigation interpretations of findings from each of the study areas, the following

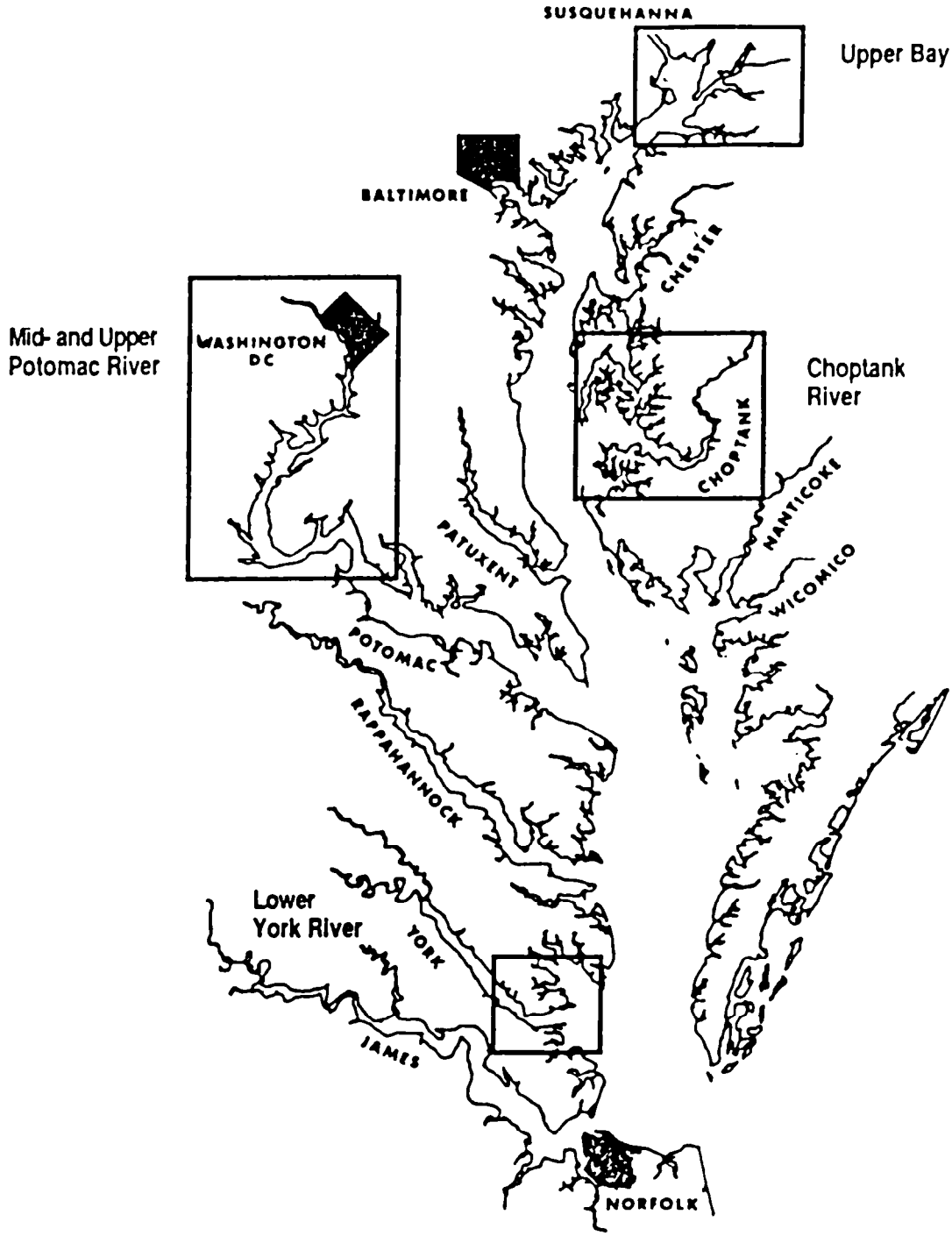

Figure 1.—Map of Chesapeake Bay showing locations of four areas used in development of SAV criteria: (left to right) mid- and upper Potomac River, tidal fresh water; Susquehanna Flats–Upper Bay, oligohaline (0.5-5 ppt); Choptank River, mesohaline (5-18 ppt); and Lower York River, polyhaline (18-25 ppt).

five SAV habitat requirements were developed for each of the bay's four salinity regimes:

- Total suspended solids (TSS),
- Light attenuation,
- Chlorophyll *a*,
- Dissolved inorganic nitrogen, and
- Dissolved inorganic phosphorus.

Restoration goals for SAV distribution were approached from a baywide and regional perspective and produced through a series of geographical over-

lays that delineated potential and actual habitat. The restoration goals are reported as acreages of nearshore bay habitat that should support SAV when established habitat requirements are met. Species diversity goals were derived by comparing the potential habitat for each species based on salinity and the actual habitat as defined through recent and historical field surveys. Baywide and regional SAV abundance and species diversity goals are critical to assessing the success of basinwide efforts to reduce nutrient inputs into Chesapeake Bay.

Summary of SAV and Water Quality Relationships

The water quality parameters defined from these studies have a functional relationship with SAV growth. Interpretation of the relationships between water quality characteristics was based on basic assumptions about the interaction between the water quality parameters and SAV. These assumptions were that:

- Total suspended solids and chlorophyll *a* increase light attenuation,
- Dissolved water column nutrients stimulate growth of epiphytes and phytoplankton, which also decreases light attenuation,
- SAV survival depends on sufficient light reaching the plants, and
- Environmental factors other than those analyzed in the SAV technical synthesis do not supercede light attenuation as the major factor determining SAV survival in Chesapeake Bay.

Table 1 presents the summary of the reported work for the four different study areas. This table serves to establish the minimum water quality characteristics for establishment and maintenance of SAV populations, rather than guaranteeing conditions for colonization by a diverse, native SAV population. Water quality conditions for a diverse, native popoulation may be more rigorous than conditions that will support only monotypic and/or exotic species populations.

The data indicated that light attenuation was strongly affected by total suspended solids (TSS) and chlorophyll *a*. Light attenuation coefficient values less than 2 m^{-1} correlated with SAV survival as do total suspended solids values less than 15 mg/L and chlorophyll *a* values less than 15 µg/L. Interestingly, the data suggested an interaction of TSS and chlorophyll *a*, as there were few data where TSS were low and chlorophyll *a* values were high.

The maximum dissolved inorganic nitrogen (DIN) values supporting SAV growth were 0.14–0.28 mg/L (except for the tidal fresh and ologohaline areas) and 0.01–0.03 mg/L for dissolved inorganic phosphorus (DIP). Low values of both DIN and DIP were found necessary for SAV survival in mesohaline and polyhaline areas while, in low salinity areas, DIN did not appear to play a critical role in defining SAV habitat quality.

Restoration Goals

Results of the systematic inclusion of all areas in the Chesapeake Bay and tributaries less than 2 meters deep revealed approximately 300,000 hectares (741,000 acres) of bottom that could potentially support SAV given appropriate water quality conditions. Some of this habitat represents areas that would be highly unlikely to ever support SAV because of its exposed nature; excluding these areas yielded 250,000 hectares of potential habitat. In 1989, the annual monitoring of baywide SAV showed approximately 25,000 hectares (61,750 acres) of bottom covered with SAV (Orth and

Table 1.—Habitat requirements for the Chesapeake Bay SAV by salinity regime.

SALINITY REGIME (SAV* TARGET SPECIES)	TSS* (mg/L)	LIGHT ATTEN. COEF. (m^{-1})	CHL *a** (µg/L)	DIN* (mg/L)	DIP* (mg/L)	CRITICAL LIFE PERIOD(S)
Tidal fresh *(Vallisnena americana)*	< 10	< 2	< 15	< 1.5	< 0.01	April–early June; late August–September
Oligohaline *(Vallisnena americana)*	< 15	< 2	< 15	< 1.5	< 0.01	April–early June; late August–September
Mesohaline *(Potamogeton pectinatus, Potamogeton perfoliatus, Ruppia maritima)*	< 15	< 1.5–2	< 10–15	< 0.14	< 0.01	May–October
Polyhaline *(Zostera marina)*	< 15	<2	< 15	< 0.28	< 0.03	Spring (9°-23°) Fall (25°-13°)

*SAV = submerged aquatic vegetation, TSS = total suspended solids, CHL *a* = chlorophyll *a*, DIN = dissolved inorganic nitrogen, DIP = dissolved inorganic phosphorus

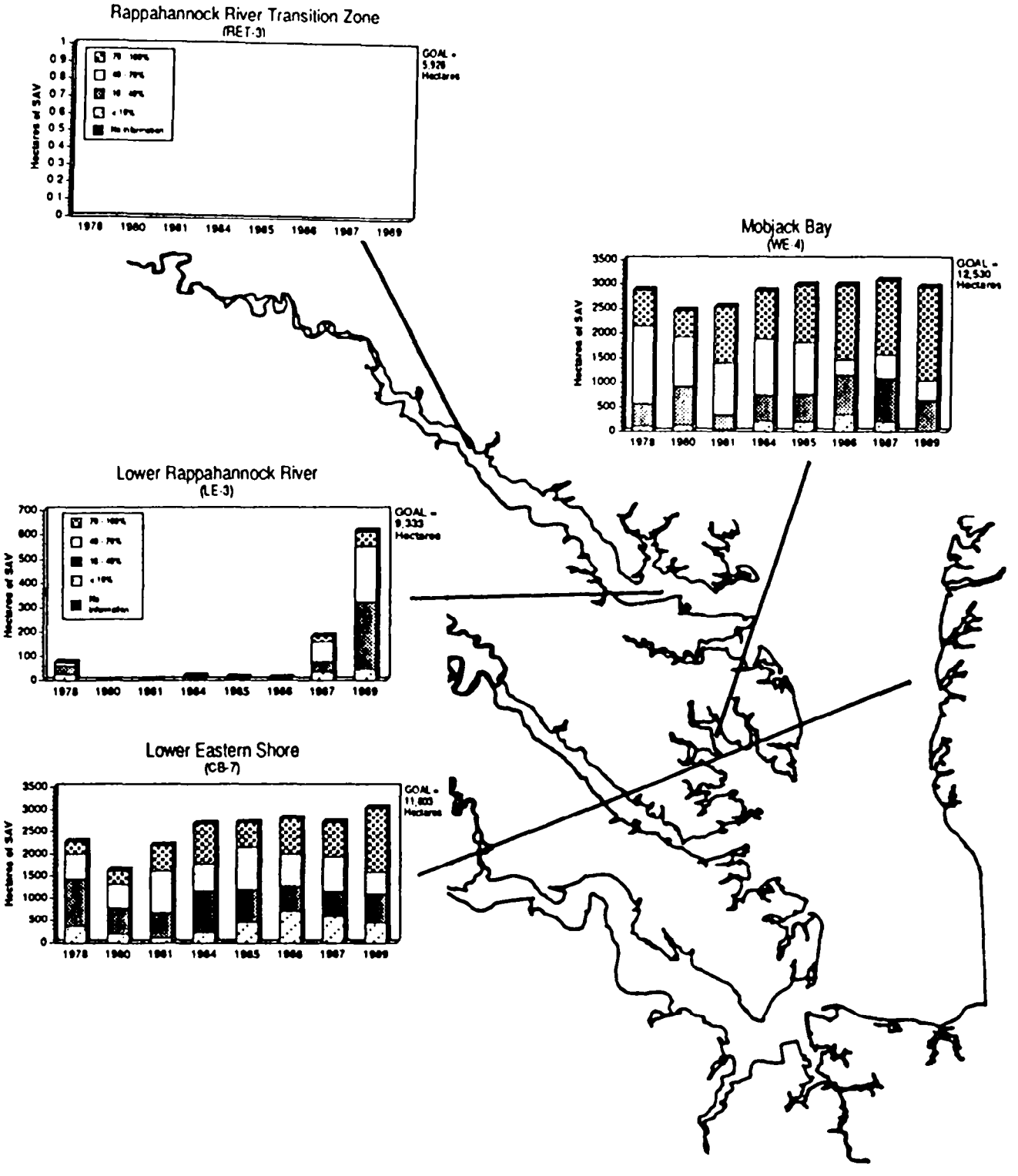

Figure 2.—Trends in SAV abundance for four sections in the lower Chesapeake Bay showing amount of SAV in different density classes (<10%, 10-40%, 40-70%, and 70-100%) from 1978 through 1989. Restoration goal for each section is presented in upper right corner of each locator box. Letter and number combination given below each location name refers to U.S. Environmental Protection Agency-derived Chesapeake Bay segment.

Nowak, 1990) or 10 percent of the potential habitat. Data for four representative sections of the bay are presented in Figure 2, which shows trends of SAV abundance for the previous decade as compared to the restoration goal for that section. Current abundance in these sections ranges from 0 to 25 percent of the potential bottom.

A comparison of SAV annual abundance patterns, habitat requirements, and water quality monitoring data from 145 water quality stations has allowed verification of the applicability of SAV habitat requirements to define conditions necessary for revegetation, survival, and growth of SAV. In 1987, 84 percent of the water quality monitoring stations characterizing areas with SAV had seasonal water quality that met four or all of the five habitat requirements. In areas where SAV was absent, 74 percent of the stations had water quality conditions that met less than four of the five habitat requirements. In 1989, 72 percent of these stations had seasonal water quality conditions that met four or all of the five habitat requirements. More than 86 percent of the stations characterizing areas where SAV was absent had seasonal water quality that met less than four of the five habitat requirements.

Conclusions

The relationships of light attenuation, chlorophyll *a*, total suspended solids, and dissolved inorganic nitrogen and phosphorus with SAV survival provide an empirically derived, real world solution to the problem of determining water quality characteristics for SAV survival. Laboratory and modelling studies have augmented the field-derived data.

One of the more intriguing elements of the technical synthesis was the close similarity in the values identified for TSS, chlorophyll *a*, and light attenuation for all salinity regimes of the Chesapeake Bay. This suggests that growth and survival of the plants, despite their location in the bay, all respond to environmental water quality within a small range of values. This response may allow for baywide management strategies rather than basin-by-basin control. However, because response to nutrient concentration depended on location (fresh water versus brackish water) nutrient reduction strategies may vary depending on the salinity regime.

The most critical aspect of this work is the relationship of these habitat characteristics to the development of revised or enhanced water quality standards to protect living resources. This is a difficult task because it requires a thorough understanding of all the sources and sinks of the different nutrients and sediments entering Chesapeake Bay. In particular, understanding the mechanisms and rates of transformation of source material to what is measured in the water column, in each salinity regime of the bay, is crucial to these revised standards.

If habitat requirements developed for SAV (or other species), such as nutrients or light attenuation, are linked to water quality standards, a different approach to developing these standards must be used other than LC_{50} measures and assessments of chronic toxicity. Understanding critical habitat requirements, manipulative field and laboratory tests of these requirements, and field validation of the experimental results is necessary to developing realistic water quality criteria for these parameters.

Lastly, there must be continuous interactions and feedback between the scientists who develop the habitat criteria for individual species and the managers who are responsible for regulations that ultimately protect, restore, and enhance the living resources. Continual monitoring of water quality and living resources, coupled with specific restoration plans and goals, is paramount if these resources are to be a part of our future.

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