EFFECT OF TIMING OF EXTREME STORMS ON CHESAPEAKE BAY SUBMERGED AQUATIC VEGETATION

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ABSTRACT

The Chesapeake Bay Estuarine Water Quality Model was used to assess the effect of extreme storm events (≥100-year storms) in different seasons on submerged aquatic vegetation (SAV). For this analysis, a three-year portion (1985–1987) of the ten-year (1985–1994) calibration period was simulated, including the November 1985 Hurricane Juan storm. Hurricane Juan was a 100-year storm in the basins of the Potomac and James rivers. The simulated November 100-year storm event was compared with other scenarios, in which an equivalent 100-year storm is simulated in the spring, summer, or autumn. These scenarios indicated that the severity of extreme-storm SAV damage depends on storm timing relative to the SAV growing season. Model estimates showed that an extreme storm can cause significant damage if it occurs in months of high SAV shoot biomass, but has no significant impact on SAV if the storm takes place in the winter or in other periods outside of the SAV growing season.

INTRODUCTION

Submerged aquatic vegetation (SAV) is important for crab, fish, and other aquatic habitats in the Chesapeake estuary [1]. Sufficient light at an appropriate depth is essential for the growth of these plants. Suspended sediment blocks light to SAV, as does excessive nutrient input that causes phytoplankton and epiphytic algae light attenuation sufficient to impair SAV growth. Suspended sediment is a major component of light attenuation and is the major impairment to SAV restoration in many regions of the Chesapeake Bay [1, 2]. Upland loads and erosion of shoreline are two major sources of suspended sediment in the Chesapeake estuary.

Sediment loads delivered to the Bay by extreme storms in just a few days are comparable to annual average sediment loads. In the last several decades, the Bay has experienced extreme storms or events that have influenced water quality and SAV to a greater or lesser extent [3, 4, 5]. An example of a high level of persistent negative influence on water quality and SAV is the June 1972 event of Hurricane Agnes [5]. Thought to be a key event in the long-term degradation of the Chesapeake SAV resource "... all [SAV] decreased significantly through 1973. . . eelgrass decreased the most (89%). . . For all species combined the decrease was 67%." [5].

In contrast, a January 1996 event on the Susquehanna led to flooding on the same scale as Agnes due to a period of warmer weather and extensive rain on snowpack, as well as the formation and subsequent breaching of an ice dam. This extreme storm had little discernible influence on Chesapeake water quality and SAV beyond the immediate event, though the storm had flows and sediment loads comparable to Agnes [3]. The June 1972 Agnes event delivered an estimated 30 million MT (metric tons) and the January 1996 event brought in 10 million MT of silts and clays, each over a period of days compared to an annual average fine-grain sediment load of about 1 million MT for the Susquehanna. This work uses the Chesapeake Bay Estuarine Model to assess the differential impacts of extreme storms that occur in different seasons on SAV.

METHODS

The year 2002 version of the Chesapeake Bay Estuarine Model (CBEM) [6] is used to model the response of SAV to nutrient and sediment loads. The CBEM is a coupled three-dimensional Hydrodynamic Model and Water Quality Model [6, 7]. The Water Quality Model is simulated in a 15-minute time step, driven by hydrodynamic forcing in a two-hour interval, with daily inputs of nonpoint sources and other loads. The model was calibrated over a ten-year period (1985–1994) [6].

Water quality and SAV responses to flow and loads were successfully simulated by both the Chesapeake Bay Watershed Model [8] and the Water Quality Model [6] for the calibration period of 1985–1994, including Hurricane Juan, a 100-year storm occurring in November 1985. The following points describe three important components of the model in this work.

1) The Water Quality Model simulates light extinction (K_e) due to water, dissolved organic matter (DOM) also know as "color," volatile suspended sediment (VSS), and inorganic suspended sediment (ISS) [6, 9]:

$$K_e = a^1 + a^2 * ISS + a^3 * VSS \quad (1)$$

where:

a_1 = background attenuation from water and DOM
a_2 = attenuation from inorganic solids
a_3 = attenuation from organic suspended solids

2) The simulated SAV production is light, temperature, and nutrient dependent. The SAV submodel simulates three major components: shoots, roots, and epiphytes. Production transformation between shoots and roots is considered. The simulated shoot reflects the above-ground abundance of SAV. The following equation is shoot simulation in the SAV submodel in the CBEM [9]:

$$\frac{d\,SH}{d\,t} = [P - (1\text{-}Fpsr) - R - SL]\,SH + TrsRT \quad (2)$$

where:

SH = SAV shoot biomass; (g C m^{-2});
t = time (d);
Fpsr = fraction of gross production routed from shoot to root;
P = production (d^{-1});
R = shoot respiration (d^{-1});
SL = sloughing (d^{-1});
Trs = rate at which carbon is transported from root to shoot (d^{-1}).
RT = root biomass (g C m^{-2}),

3) The setup of scenarios with a 100-year storm in different seasons is as follows:

The November storm scenario simulates the actual November, 1985 Hurricane Juan event. Although only a Category 1 hurricane, Juan ranks as the eighth costliest hurricane to strike the U.S. mainland. In the Chesapeake, Hurricane Juan constituted a 100-year storm that caused flooding primarily in the Potomac and James watersheds. The other scenarios simulate an extreme storm occurring in other months, including May, July, and September in 1985, or a simulation of no storm in the year 1985.

Hurricane Juan hit the Chesapeake region on 3 November in 1985, and lasted for 3 days as a high rainfall event centered in the upper watersheds of the Potomac and James rivers. The high river flows from this rainfall event persisted for about 2 weeks (Figure 1). The hydrology and nonpoint load of one spring-neap tide cycle (about 14 and a half days) during 1–15 November in 1985 were used as the "storm input" for other scenarios. For example, the May Storm Scenario uses the equivalent "storm input" in May. In the meantime, the September low-flow condition in one spring-neap tide cycle was used as the "no-storm condition" input during 1–15 November for the May Storm Scenario (Figure 2). The 14-and-a-half-day storm substitution matches the cycles of the spring-neap tides (from the 1985 tide record) [10]. Since point source load input for the Water Quality Model input is monthly and varies only a trivial amount during among the 1985 months, point source load is not adjusted for these scenarios.

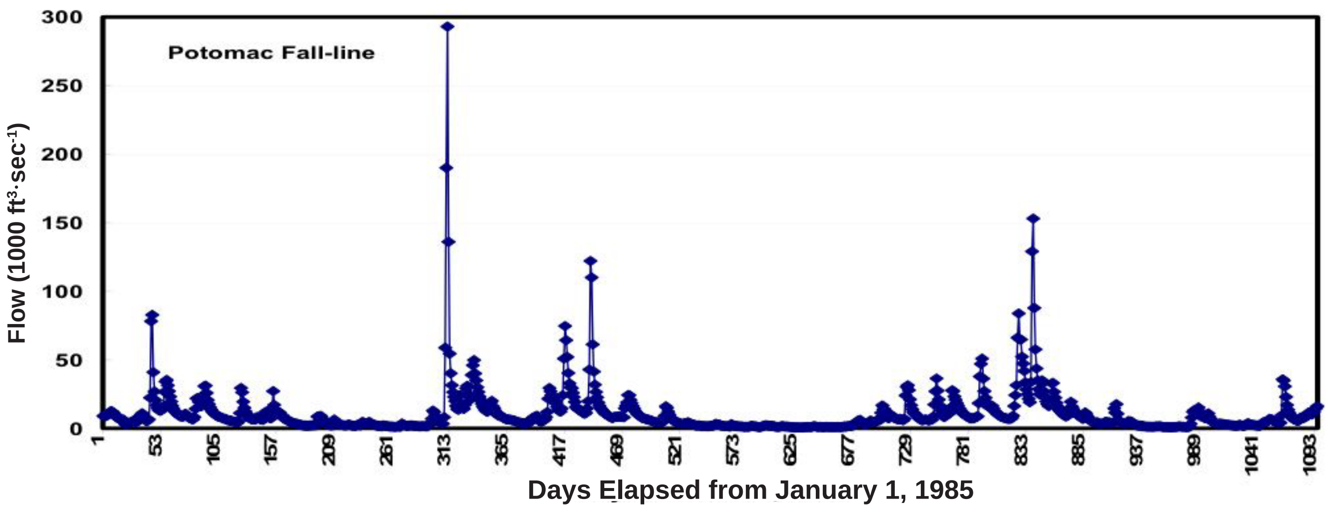

Figure 1. Daily flow at the fall-line of the Potomac River (1985–1987).

The CBEM is simulated for 3 years from 1985 to 1987. All of these scenarios use the same hydrology and loading inputs in the simulation during 1986 and 1987.

RESULTS AND DISCUSSION

Effect on Water Clarity by Hurricanes

In the tidal-fresh Potomac region, light attenuation (K_e) increases abruptly due to the simulated 100-year storm event (Figure 3). Four light attenuation peaks (K_e near 100 m^{-1}) correspond to the simulated May, July, September, and November storms. The light attenuation remains high (K_e >4 m^{-1}) for weeks after the storm, most significantly (e.g., K_e >8 m^{-1}) in the first week after the storm. The graph's open circle symbol denotes the No-Storm Scenario, which has no extreme high peaks in light attenuation. However, K_e in many days is higher than the optimal level to SAV communities (tidal-fresh SAV, K_e <2.0 m^{-1} at 1-m depth). The fluctuation of K_e, 2–8 m^{-1}, in the No-Storm scenario is due to minor storms in 1985–1987. After day 320, all five scenarios have almost the same K_e levels. The simulated long-term effects, other than the storm event, are essentially the same in all five scenarios. Figure 4 shows the TSS concentration peaks, which are almost entirely

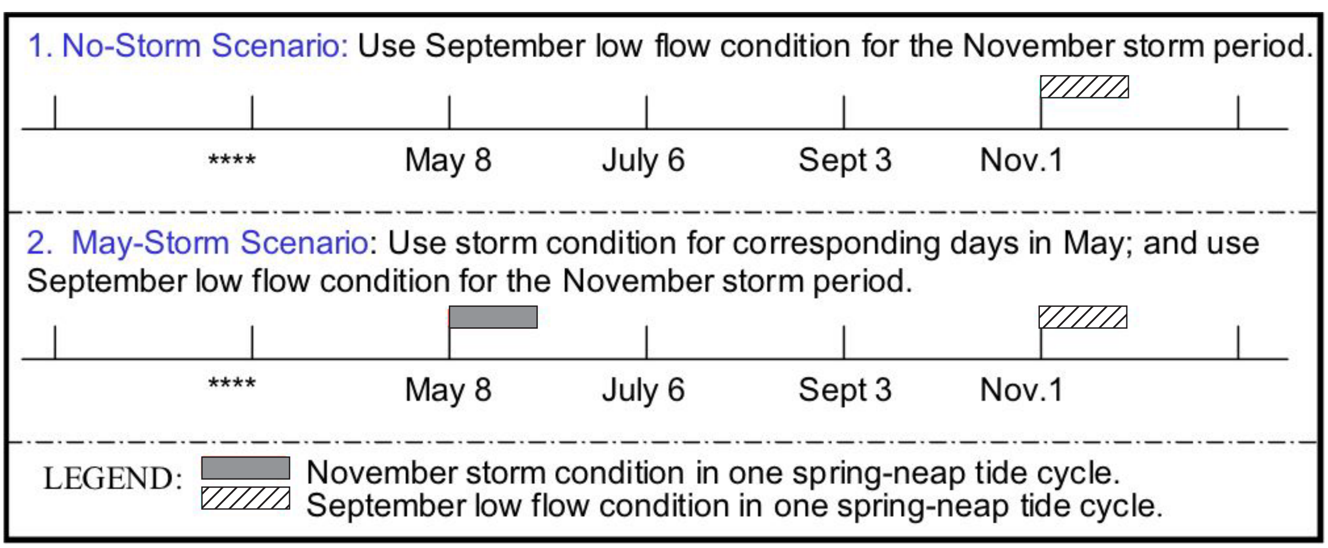

Figure 2. Example of the method used to simulate the Hurricane Juan event in May.

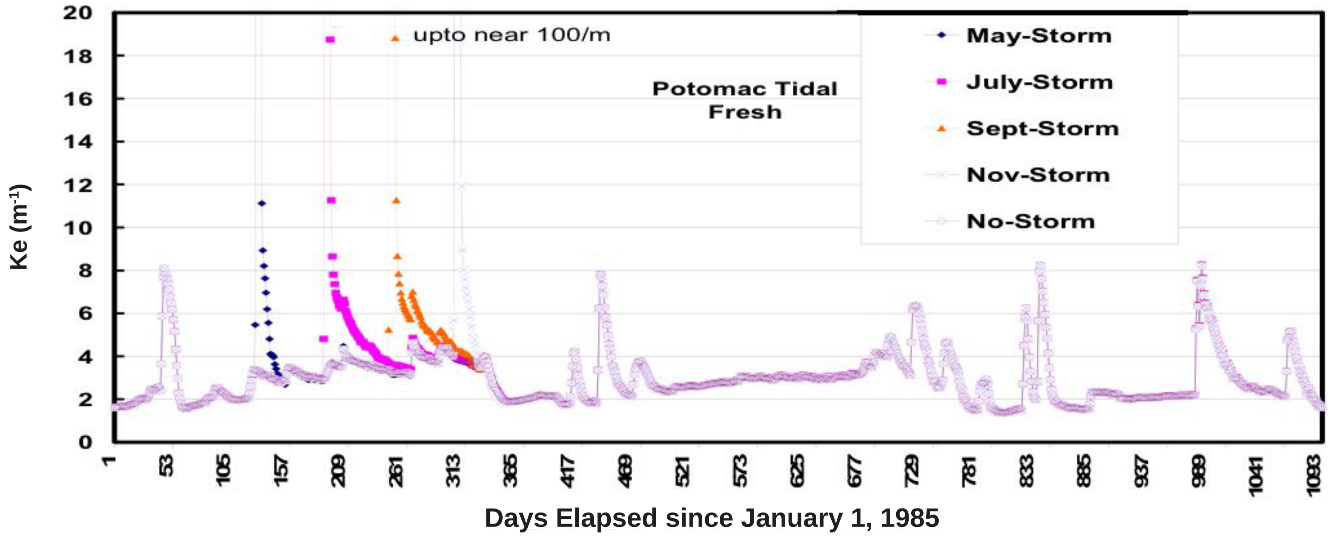

Figure 3. Ke in the Potomac tidal fresh region for five scenarios.

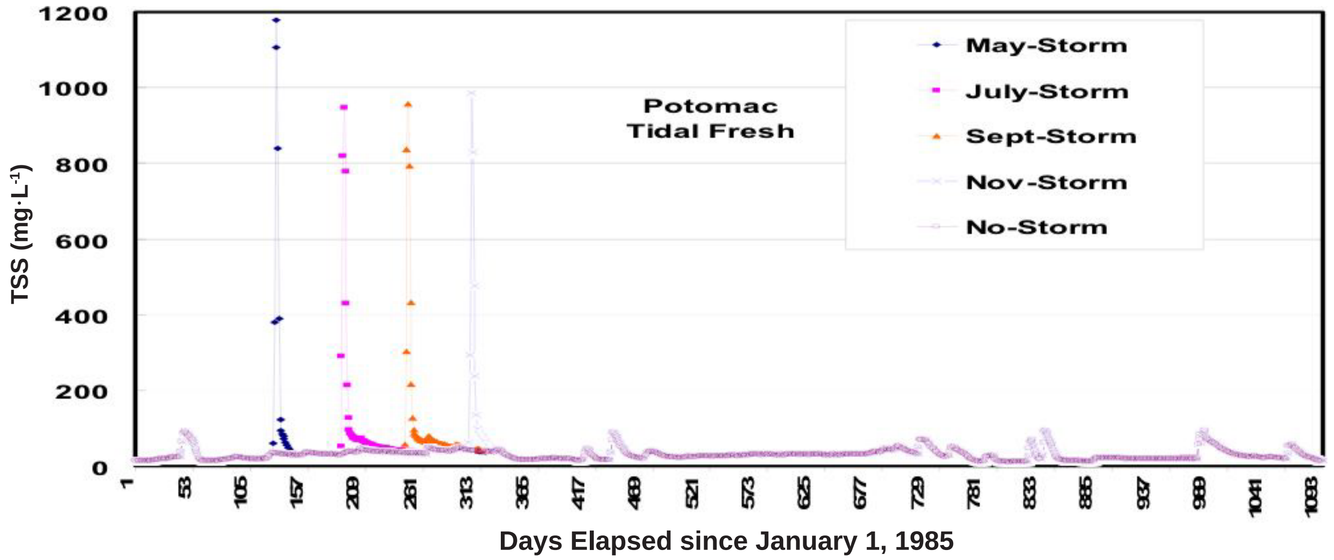

Figure 4. TSS in the Potomac tidal fresh region for five scenarios.

due to inorganic suspended solids, for the different scenarios.

Effect of Extreme Storms in Different Seasons on SAV

Tidal-Fresh Regions

Figure 5 and Figure 6 are simulated monthly SAV biomass from 1985 to 1987 in the Potomac and James rivers' tidal-fresh regions. Generally, the shoot biomass of the tidal-fresh SAV community peaks during September and October with a prominent growing season of shoot biomass from May to November (Figure 7) [9, 11]. The tidal-fresh SAV community is simulated in both the Potomac and James tidal-fresh regions (Figures 5 and 6).

The Potomac and James tidal-fresh (Figures 5 and 6), SAV biomass was decremented in the first year by the simulated May, July, and September extreme storm. The November extreme storm has no more effect than the No-Storm Scenario. After the peak in September, SAV growth follows the natural decline of shoots toward winter; therefore, the response of SAV to a post-peak storm is less than the response of SAV to a storm during or before the peak.

SAV biomass was also affected in the second year in the May, July, and September scenarios and again the effects of the November storm were indiscernible from the No-Storm Scenario (Figures 5 and 6). The second-year influence of the May, July, and September scenarios probably results from decreases in simulated overwintering SAV root due to the Fpsr and Tsr terms in Equation 2.

This decrease suggests that lower shoot survival during the winter due to the effect of storm before winter results in the apparent lower biomass in the following year for the corresponding storm scenario.

Polyhaline Region

Figure 8 shows simulated monthly SAV biomass from 1985 to 1987 in the lower estuary polyhaline James River. The polyhaline SAV community peaks in July and again in October, with a prominent growing season of shoot biomass occurring from April to November [9, 11], as shown in Figure 9.

In the James lower estuary polyhaline region, simulated SAV shoot biomass is decreased by the May, July, and September simulated extreme-storm events but not by the November simulated extreme storm (Figure 8). In this storm, the simulation of

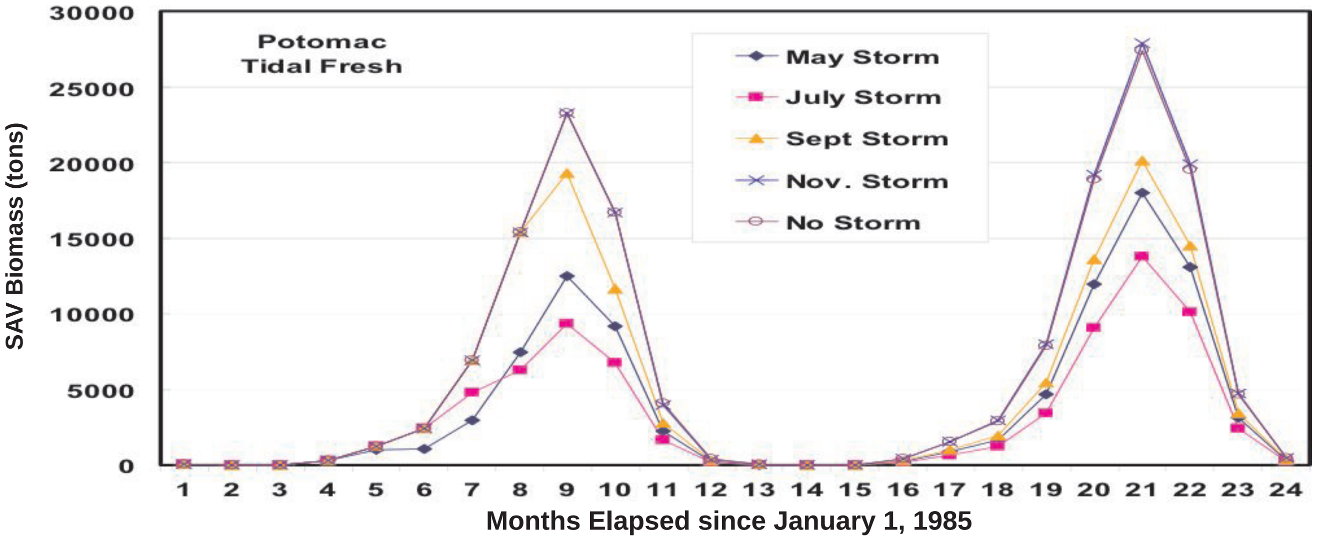

Figure 5. SAV biomass in the Potomac tidal fresh region for five scenarios.

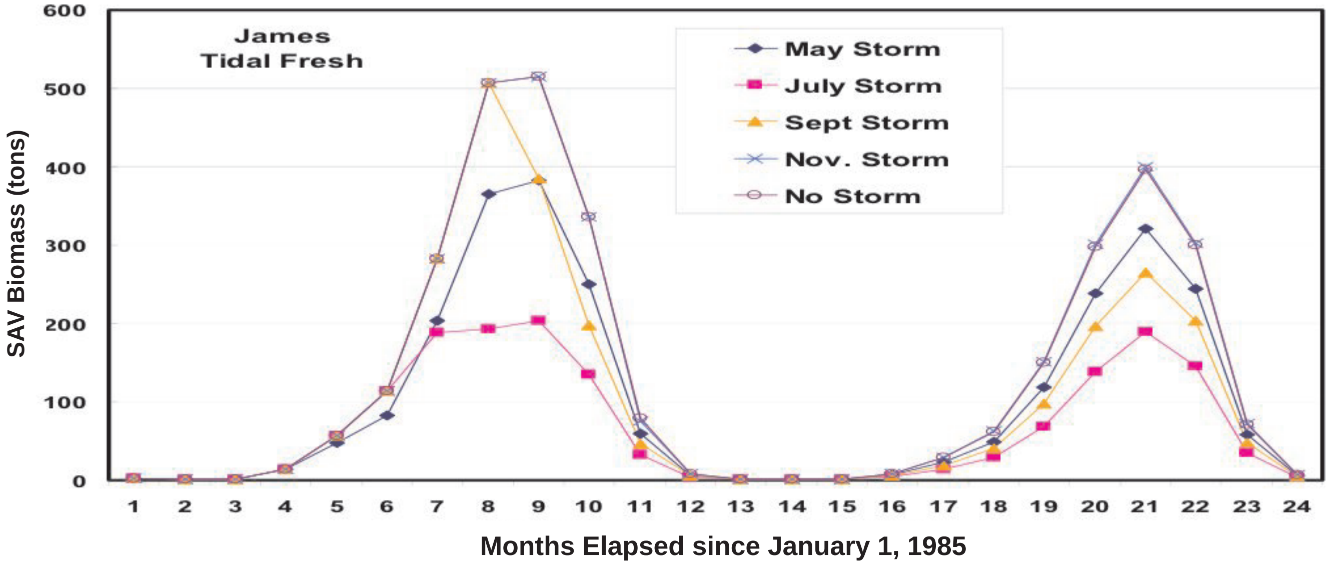

Figure 6. SAV biomass in the James tidal fresh region for five scenarios.

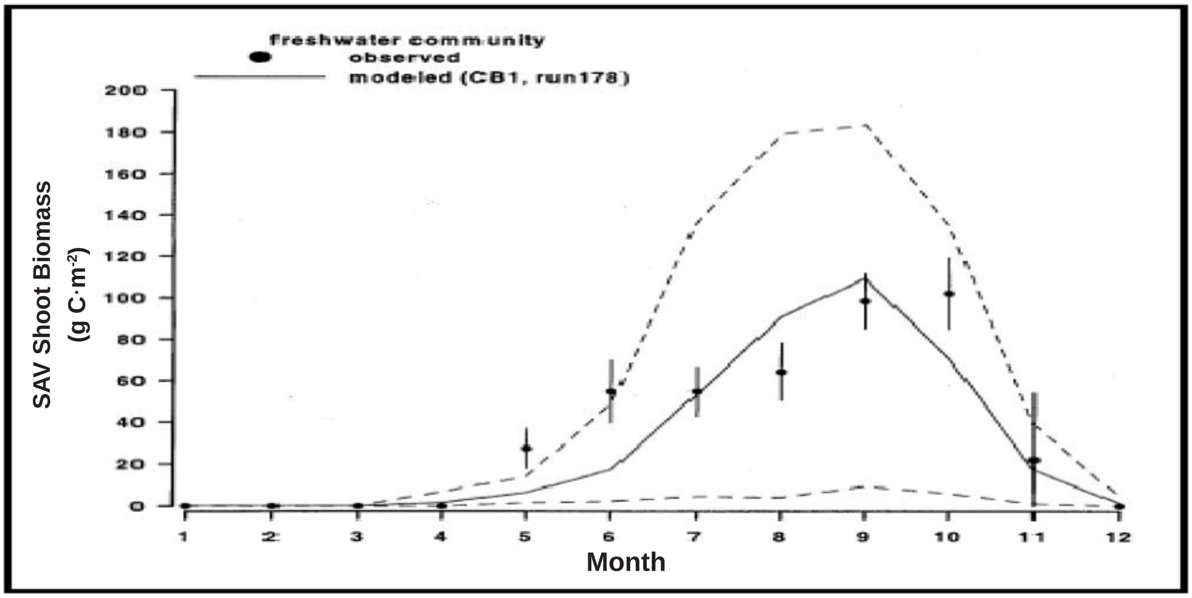

Figure 7. Simulated and observed SAV shoot biomass for a tidal fresh SAV community. Modeled (mean [solid line] and interval encompassing 95% of computations [dashed line]) and observed (mean [dot] and 95% confidence interval [vertical line through dot]) freshwater SAV community (above-ground shoot biomass only). Observations from Moore et al. [11]. Model simulation from the Susquehanna Flats (Segment CB1TF) using the 10,000-cell 1998 version of the Water Quality Model. Source: Cerco et al. [9].

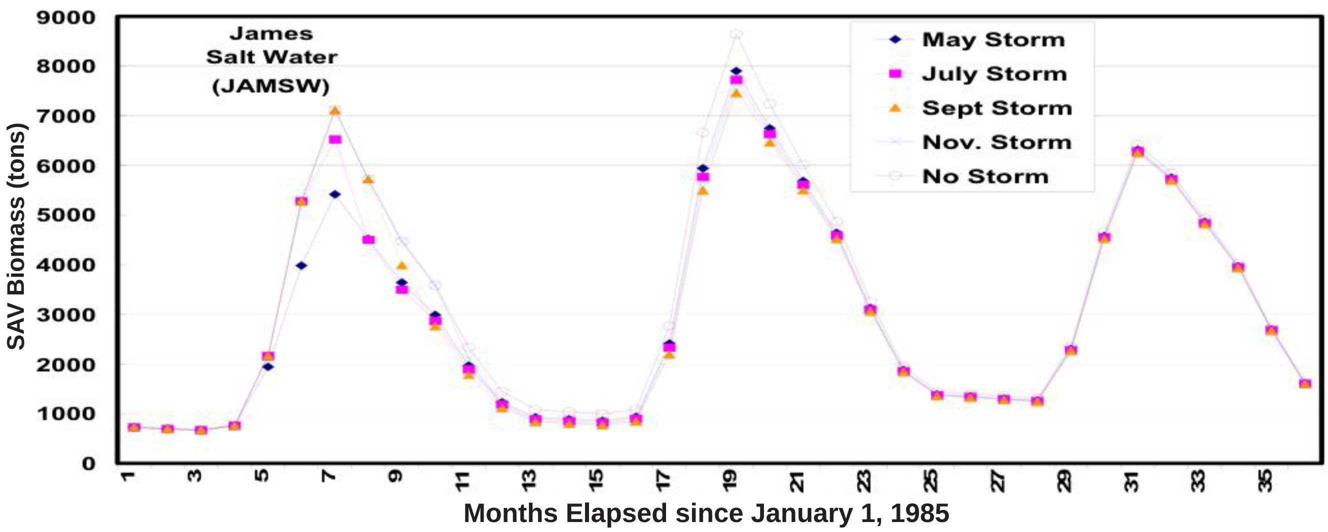

Figure 8. SAV biomass in the James lower estuary region for five scenarios.

the first year's effects is the same in the tidal-fresh and polyhaline SAV communities. A difference occurs in the second year when the simulated polyhaline SAV shoot biomass is influenced by the November extreme storm.

In all cases, by the third year the effect of simulated extreme storm events on SAV shoot biomass is unobserved.

CONCLUSIONS

Based on the model scenarios, the following conclusions were reached:

- Extreme events, such as hurricanes, deliver high sediment loads and reduce clarity below that level required to support SAV, often over a period of weeks.

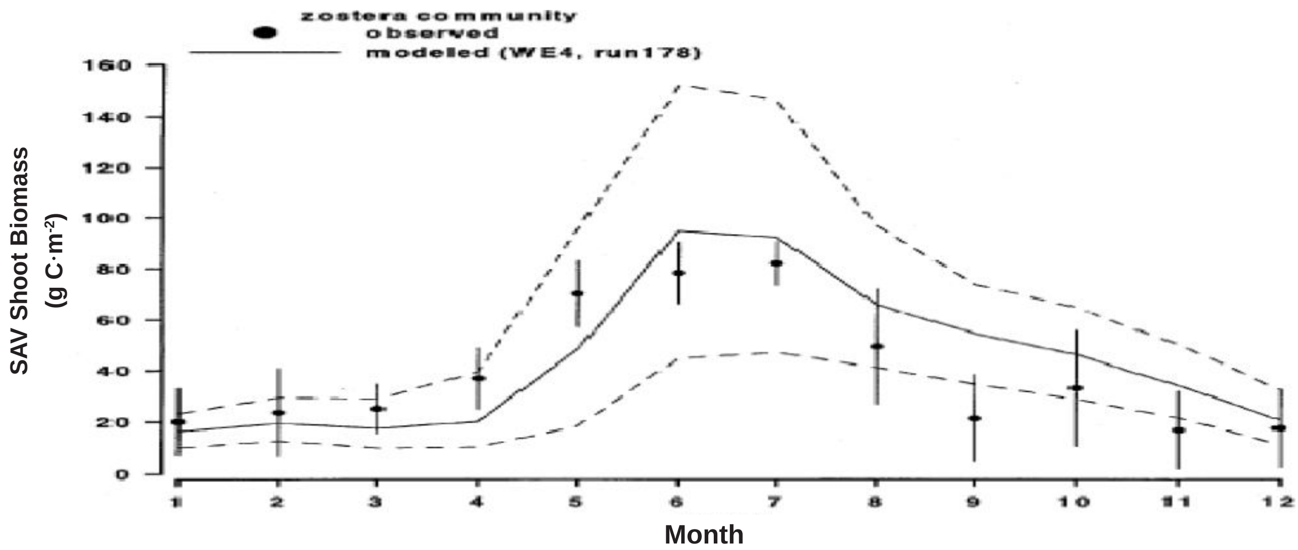

Figure 9. Simulated and observed SAV shoot biomass for a polyhaline SAV community. Modeled (mean [solid line] and interval encompassing 95% of computations [dashed line]) and observed (mean [dot] and 95% confidence interval [vertical line through dot]) polyhaline SAV community (*Zostera* above-ground shoot biomass only). Observations from Moore et al. [11]. Model simulation from Mobjack Bay (segment MOBPH, formerly WE4) using the 10,000-cell 1998 version of the Chesapeake Bay Water Quality Model. Source: Cerco et al. [9].

- Extreme storm events during the SAV growing season are detrimental, particularly during periods before peak shoot biomass.
- Extreme storms during the SAV growing season, but after the shoot biomass peak, are estimated to be less detrimental. In the simulated tidal-fresh SAV community, the November extreme event has no effect on SAV shoot biomass as the shoot biomass during this time is already in a normal, natural decline leading to an absence of SAV shoot biomass by December.
- In tidal-fresh SAV communities, the degree of diminution of SAV shoot biomass carries over as an "echo" of decreased SAV biomass in the second year. This effect is due to the decrease in simulated shoot biomass carried forward by a decrease in simulated shoot biomass. By the third simulated year of SAV response, the effect of extreme storms on SAV biomass is generally unobserved.
- In the simulated polyhaline James SAV community, the SAV response to extreme storms was similar to that of the tidal fresh with the exception of the November storm. In this case, the simulated November storm is close to the secondary October peak in the polyhaline SAV community shoot biomass. The resulting decreased SAV shoot biomass in November carried over to a noticeable SAV decrease during the second year.
- Timing of storms relative to SAV growing seasons causes different effects on SAV, consistent with the observations noted in the introduction [3, 4, 5], though the model does not directly simulate some of these storms.

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