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Biomass of Submerged Aquatic Vegetation in the Chesapeake Bay

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Information provided in existing field biomass and ground truth surveys of Chesapeake Bay submerged aquatic vegetation (SAV) were quantified along with 1985 to 1996 annual aerial surveys of SAV distribution and abundance to determine the community type and aboveground biomass for each SAV bed mapped in the bay during this 12 year period. Using species identifications provided through over 10,000 SAV ground survey observations the 17 most abundance SAV species found in the bay were clustered into four species associations: ZOSTERA, RUPPIA, POTAMOGETON and FRESHWATER. In addition, monthly aboveground biomass values were assigned to each bed based upon biomass models developed for each community. The biomass values of each SAV bed are now available for use along with the annual mapping measurements of bed area for evaluation of bay SAV standing stocks.

During the 1985 to 1996 period SAV standing stock increased from lows in 1985 and 1986 to highest levels during 1991-1993. High salinity communities (ZOSTERA) dominate during the winter, spring and summer. Lower salinity communities (RUPPIA, POTAMOGETON, and FRESHWATER) dominant in the fall. At peak biomass in July, total standing stock was nearly 17,800 metric tons in 1996. Minimum standing stock in December and January was about 5,000 metric tons.

Year-to-year comparisons of annual bay-wide maximum community aboveground biomass levels from 1985 to 1996 indicate that recovery of SAV in the Chesapeake Bay has occurred principally in the ZOSTERA community. Rapid growth of ZOSTERA beds occurred between 1985 and 1991 with peak biomass increasing from 9,200 to 17,800 metric tons. Nearly constant biomass levels of ZOSTERA have been observed since then. Biomass of FRESHWATER SAV beds have also demonstrated some increases while both RUPPIA and POTAMOGETON beds have fluctuated at nearly constant levels since 1985.

Currently most SAV ground survey efforts are focused in the James and Potomac rivers and the upper bay. More efforts need to be focused along the mid-bay regions of the bay's eastern shore where year-to-year changes in SAV abundance and community type can be high. In addition, one SAV species, Zannichellia palustris, which occurs in many mesohaline areas early in the spring was found to be under-represented in the aerial mapping program. Specific studies should be initiated to determine this species abundance.

BACKGROUND

Annual Aerial Survey

Baywide aerial mapping surveys of submerged aquatic vegetation (SAV) been a nearly annual survey since 1985. Published as a report (eg. Orth et al. 1997) as well as stored in a Arc/Info Geographic Information System (GIS) these data have been valuable in management of this resource, both in the permit review process, as well as from the standpoint of overall bay management. Because of the strong relationships which have been developed between the underwater macrophytes and water quality

(Batiuk et al. 1992), SAV have been chosen as one the principal indicator communities used to assess the success of bay cleanup efforts. The baywide annual aerial surveys have become the most cost effective and comprehensive tool with which to assess changes in this resource.

Included in the annual surveys is species information which has been obtained through a variety of sources, including surveys by citizens as well as environmental or regulatory agencies. Nearly all of this information is qualitative and limited to species identification and some relative abundance observations.

The aerial photographic surveys provide accurate measures of SAV bed areas that are separated into four density classes (Orth et al. 1997). While this category-type data provides a good measure of relative abundance they do not directly provide information such as SAV biomass or productivity. Measures of bay SAV biomass has become increasingly important as the capacity of researchers and managers to effectively model the bay ecosystem improves. Differences between relative cover and biomass can be important. During any particular year overall bay SAV area may increase, or decrease, or remain the same from previous years, while SAV biomass may not vary linearly with these changes in areas. A common metric such as biomass or productivity is necessary to discriminate potential changes over both spatial or temporal intervals, especially in context of the overall bay ecosystem. In addition, calibration and validation of bay simulation models which are currently being developed with an SAV component will require information of SAV mass or productivity not area or relative abundance (Cerco and Cole 1994).

Chesapeake Bay Eutrophication Models

While SAV are affected by deteriorated water quality they also are active agents in improving water quality by sequestering nutrients, filtering suspended particles and serving as a source of organic production. These inherent processes will have direct effects on secondary production within the bay system (Fredette et al. 1990). The importance of these roles have been identified both in field studies which are quantifying these differences (Moore et al. 1995), as well as in bay ecosystem models of which bay SAV have become an integral component. The tributary-enhanced version of the Chesapeake Bay Eutrophication Modeling package, under development by the Army Corps of Engineers, will for the first time include a representation of the littoral zone (Cerco and Cole 1994). Predictions based upon this modeling package will have important implications for bay resource management and pollution reduction plans. In addition, other SAV-specific ecological models for SAV communities in both the upper and lower bay (eg. Wetzel and Meyers 1994), which are being incorporated into this overall bay model, are addressing the fundamental relationships between SAV and the bay system.

The enhanced Bay Eutrophication Model will address various scenarios relating varying pollution reduction strategies to bay living resources. In that context SAV are a principal living resource with which to test and validate the model. Although the model will be spatially distributed, output will not be area-based but will be biomass-based. Therefore, the current distribution and abundance data available through the annual baywide SAV survey will not be directly applicable for model validation. A conversion is necessary from the current mapped area-density measures, to biomass-productivity values.

Area-density to Biomass-Productivity Conversions

Recently the SAV Working Group of the Chesapeake Bay Program, Living Resources Subcommittee has been asked by Dr. Carl Cerco of the Army Corps of Engineers, Vicksburg, Ms. to provide information on the biomass of SAV communities in the bay for use in the Enhanced Bay Euthrophication Model. Although data on SAV biomass in the bay are widely available, the development of relationships between biomass-productivity data and the SAV aerial mapping database are complex. While first order approximations can be made, a number of factors need to be considered in developing these relationships. Such first order approximations can lead to large errors in the estimates of bay SAV biomass and productivity. These errors may exceed the range in model predictions, leading to poor model calibration or validation. Density classes which are currently quantified in the aerial survey include a wide range of community types, species assemblages, and depth intervals. The density classification scheme in the aerial survey defines large areas with scattered, dense patches of SAV in the same class as more uniform but less densely vegetated areas. The actual biomass differences of these two different but similarly classified areas, if any, are unknown.

Much of the data which can be used to quantify the relationships between the information available in the SAV GIS and actual SAV biomass and productivity are known or have been published. They have never been integrated or synthesized to address these bay management needs, however. Currently only species presence/absence information are collected to identify SAV community types in the annual survey.

SAV Geographical Information System

SAV species, density and location data are now stored in an Arc/Info Geographic Information System (GIS) that supports the annual SAV monitoring program (http://www.vims.edu/bio/sav). While the GIS greatly facilitates the production of the annual monitoring report, it has also been designed to effectively support SAV research. In particular, once the correspondence between SAV density class photo-interpretation and actual SAV biomass is established, it can be applied to the species type, location, and density data in the GIS to estimate SAV biomass and productivity at the bed level for the entire Chesapeake Bay at different times throughout the year. The model can also be applied to the historic data, covering a span of more than 14 years.

OBJECTIVES

The overall objective of this project was to calculate the biomass for all areas of SAV mapped in the Chesapeake Bay using SAV distribution and abundance information available from annual reports, biomass information available from published and unpublished reports by Bay researchers, and species ground survey observations provided by researchers, volunteers and others in the Bay community.

To accomplish this task specific objectives which were required included:

- Using only previously available information develop appropriate SAV species associations which could be used to classify the SAV beds found throughout the bay into a small number of community types.

- Review and summarize existing biomass information and develop annual models of SAV biomass for each of these SAV community types.
- Identify and assign appropriate SAV community types to all SAV beds and calculate SAV biomass for all beds mapped in the Chesapeake Bay.
- After the start of this project it was requested by Dr. Cerco of WES who was developing a SAV/littoral zone (< 6 ft.) sub-model of the Chesapeake Bay, that, if possible, a determination of SAV biomass be developed for all SAV beds which had been mapped each year from 1985 to 1996. This was then added as a fourth specific objective.

METHODS

Development of SAV Community Types

The identification of SAV community types was based on an analysis of SAV ground survey data published in the annual SAV distribution reports from 1985 to 1997 (eg. Orth et al. 1997). These reports document the locations of the SAV species which have been identified by presence/absence censuses in field surveys performed during the growing season by agencies and individuals, including many citizens groups. This species ground truth data had not been compiled or quantified, although survey information for the years 1994-1996 had been entered into the SAV GIS. To provide the most information possible for the analysis of community types, all eleven years of ground survey information from 1985-1996 (no aerial mapping data in 1988) were digitized into the SAV GIS for use in the current study. Species information was assigned to each of the individual locations which were identified on the SAV maps in each yearly report. Chara sp., Najas flexilis, Nitella sp., Potamogeton epihydrus, Potamogeton nodosus, and Trapa natans were identified in twelve or fewer observations and therefore were not used in the determination of SAV community types.

Community types were developed from the entire ground survey database using numerical clustering analysis. Dice's coefficient of similarity (Boesch 1977) is a commonly used quantitative resemblance measure which is useful for the numerical clustering analysis of binary (presence/absence) ground truth data such as gathered in the ground surveys (Clifford and Stevenson 1975). The greater the coefficient of similarity, the more frequently paired species or groups of species occur in the database.

The overall bay SAV species distribution, which is controlled in most cases by salinity tolerance (Stevenson and Confer 1978), was then used along with the clustering analysis and the abundance data in the development of the specific community types.

Assignment of Individual SAV beds to Community Types

Since yearly ground truth species information was not available for each individual SAV bed a procedure was developed to classify each mapped bed into a specific community type for each year of the aerial survey. In most areas of the Bay and its tributaries, SAV which are located near one another tend to be composed of the same species. This is due to the dominant effect salinity has on species distributions in the bay (Stevenson and Confer 1972). Therefore, to a certain degree, beds can be assigned to the community type of the nearest point where field survey information is available. This confidence decreases with increasing distance from a survey location. To determine the maximum distances that can be used with confidence, the distribution of field observations for 1994 and 1995 were analyzed spatially using Arc/Info GIS software. First, the over-water distance between reported survey locations was computed and used to determine the percentage of observations within a particular distance of each other that share the same community type. Since this relationship can vary greatly throughout the Bay with factors such as the local salinity gradient, this calculation was applied to each of the 44 Chesapeake Bay Program (CBP) segments to estimate the maximum distance within which at least 90% of the ground survey observations were of the same community type. An example of this analysis for CBP Segment CB6 is presented in Figure 1. In this particular CBP segment all SAV ground truth locations surveyed in 1994 and 1995 were of the same community type when they occurred within approximately 8 km of each other. A 90% similarity was found up to distance of approximately 11 km apart with a linear decrease in similarity with increasing distances up to 30 km. An increased similarity at distances beyond 30 km was likely due to comparisons between beds in separate tributaries where salinity regimes were comparable.

A step-wise procedure was next used to assign a community type to each bed mapped in the annual aerial surveys from 1985 to 1996:

- First, beds that were directly surveyed in the current year were assigned to a community type based on the species reported;
- Second, beds were assigned to the community type of the nearest field observations of the current year which were located within the 90% similarity distance computed for the CBP segment where the bed was located;
- Third, beds that were directly surveyed in the preceding year were assigned to a community type based on the species report at that time;
- Fourth, beds were assigned to the community type of the nearest field observations made the previous year within the 90% similarity distance computed for the CBP segment where the bed was located;
- Fifth, beds that were directly surveyed in the subsequent year were assigned to a community type based on the species reported then;
- Sixth, beds were assigned to the community type of the nearest field observations made the subsequent year within the 90% similarity distance computed for the CBP segment where the bed was located;
- Seventh, all remaining SAV beds were individually assigned to a community type based on the overall information provided by the entire ground survey data set.

Development of SAV Biomass Models for Each Community Type

Available published and unpublished studies containing SAV biomass data from the Chesapeake Bay region were reviewed to determine average monthly biomass values for individual species (Table 1). Only data from studies in which SAV aboveground biomass was reported at least periodically in units of mass per area throughout the growing season were selected for use. Belowground measurements were not available for most species and therefore monthly models for this component of biomass were not attempted. Species specific aboveground biomass values were converted from wet weight or other reported units to dry mass per unit area by first transforming each study's data to their proportions of the study's maximum values for each species reported. These proportions of seasonal maxima were then applied to an overall maximum seasonal value in units of grams dry mass per m2 that was calculated using the subset of studies that reported results in units of dry weight per area. In those studies where field biomass sampling was not conducted monthly, values for months not sampled were estimated by linear interpolation. The mean monthly biomass values were determined by averaging the monthly values assuming equal area of each of the principal species comprising a community type. The FRESHWATER model was based on average monthly estimates of H. verticillata, M. spicatum, and V. americana and the POTAMOGETON model was based on biomass measurements of P. perfoliatus and P. pectinatus. The ZOSTERA and RUPPIA community models were based on single species biomass estimates.

Application of SAV Biomass to Aerial Photographic Cover Classes

Annual aerial photographic surveys of SAV coverage are summarized (eg. Orth et al. 1997) as SAV areas which have been assigned to ranked density classes based upon photo-interpretation using a Crown Density Scale adapted from Paine, 1981 (Fig. 2). It was necessary to quantify how these density classes corresponded with measurements of SAV ground truth biomass so that the aerial survey data could be used to determine SAV biomass baywide. To accomplish this task a data set (Moore, Orth and Dennison unpubl.) consisting of point-intercept transect measurements collected during the summer of 1990 at a range of locations throughout the bay (Fig. 3) was used. This data was comprised of point-intercept measurements obtained by divers at 10 m intervals along transects oriented perpendicular to the shore across SAV beds of different densities and species composition. Each point sample consisted of triplicate estimates of bottom cover and depth within randomly placed 0.25 m2 sampling rings. Individual ground cover transects were then separated into segments based upon the published photo-intrepreted density class zones comprising each area (Orth et al. 1996).

Calculation of Monthly SAV Bed Biomass

Monthly aboveground biomass for each individual SAV bed, or bed segment where more than one density zone comprised a bed, was calculated by the following:

Monthly Biomass = Mb * Cc * Ba

Where,

Mb = Model monthly biomass for assigned community type (gdm m-2)

Cc = Photo-interpreted density class to ground cover conversion

Ba = Bed area (m2)

RESULTS

SAV Community Types

Figure 4 presents a summary of the clustering analysis of all 11 years of ground survey information (10,023 observations) in dendrogram form. Dice's coefficients between individual species or species groups are represented by the vertical lines. Table 2 presents a matrix of the number of observations reporting pairs of individual species as well as the number of observations reporting only a single species. For example, Z. palustris (Zp) was found growing with C. demersum (Cd) 54 times and Z. marina (Zm) 11 times, but in monospecific stands 874 times. V. americana (Va) was observed growing with M. spicatum (Ms) 1201 times, in monospecific stands 209 times, but never with Z. marina. The degree of resemblance between pairs of species based upon these observations of co-occurrence is presented in Table 3.

Figures 5a-5n present the recorded occurrences of each of the individual species from 1985-1996. Although Z. marina and R. maritima are highly associated (Fig. 4; Table 3) R. maritima is usually a minor component of SAV beds in the lower bay, which are typically dominated by monospecific stands of Z. marina (Moore et al. 1995; Orth and Moore 1983; Table 2). R. maritima, however, has a wide salinity tolerance and has also been found throughout the mid-bay as well as the Patuxent and Potomac Rivers where it occurs in many monospecific beds (Fig. 5b; Table 2). Based upon this additional information Z. marina and R. maritima can be further divided into two species groups with all beds containing Z. marina assigned to a ZOSTERA community type and beds containing R. maritima, but not Z. marina assigned to a RUPPIA community type.

Z. palustris, Potamogeton perfoliatus, and Potamogeton pectinatus were found throughout many of the same mid-bay regions, although usually not at the same locations. Z. palustris typically grows in monospecific beds early in the year and it is usually not found in most areas by mid-summer. In fact, nearly all of the beds of Z. palustris which are located by ground truth surveys early in the year (Fig. 5n) do not appear on the aerial photography surveys of these regions in August (Orth et al. 1996). Although Z. palustris has been found to be somewhat associated with both Potamogeton species (Table 2), the coefficient of similarity is low (Fig. 4; Table 3). Since there are few beds of SAV which consist principally of Z. palustris in the aerial mapping database (eg. Orth et al. 1997) the abundance of this species cannot be well quantified. However, since P. perfoliatus and P. pectinatus are found in a variety of mixed and monospecific stands (Figs. 5c-5d; Table 2), all beds reported with either P. perfoliatus or P. pectinatus, but no Z. marina or R. maritima, were assigned to a POTAMOGETON community type.

Freshwater regions of the upper bay and the upper Potomac River are vegetated with a diverse assemblage of SAV (Figs. 5e-5m) which are clustered in a large group of 11 species ranging from Najas sp. to C. demersum (Fig. 4). Of these 11 species M. spicatum, H. verticillata, and V. americana are the most abundant. H. verticillata and M. spicatum had the highest co-occurrence of any two species reported with over 1450 observations reporting both species (Table 1). V. americana was found to co-occur with H. verticillata and M. spicatum 877 and 1201 times, respectively. All beds not assigned to the ZOSTERA, RUPPIA, or POTAMOGETON community types were assigned to a FRESHWATER community type.

Table 4 presents the species associations for all four community types including all species where occurrence exceeded 10% of observations. Figures 6a-6d display the SAV bed field observations after assignment to community type. Observations of FRESHWATER and POTAMOGETON communities dominate the upper Bay and upper tributaries, while RUPPIA was found throughout much of the bay excluding the most freshwater tidal regions. ZOSTERA dominates the lower bay.

SAV Biomass

Figure 7 illustrates the relationship between sampling ring ground cover estimates and the photo-interpreted density classes for all transect segments. The relationship was quite linear. However, the slope of the relationship was less than one suggesting that, while consistent, the aerial photo-interpretation tends to under estimate ground cover at lower SAV densities and over estimate at higher densities. No consistent effects of community type or depths of SAV growth on the relationship between ground cover and density class assignments could be determined. Therefore, density class to ground cover conversions were applied consistently across all SAV beds.

SAV Biomass Models

Each of the four SAV communities demonstrated a distinctive pattern of shoot biomass (Fig. 8). The ZOSTERA and RUPPIA communities exhibit peaks of shoot biomass in the early and late summer, respectively, and both maintain aboveground shoot biomass throughout the winter. Shoot growth for ZOSTERA was evident as early as February and rapid shoot dieback was apparent beginning in July with a second short period of growth in the fall. RUPPIA did not demonstrate a significant increase in shoot biomass until June and it subsequently reached a maximum standing crop in August of approximately 100 gdm-2 after which it declined to winter levels of 20-25 gdm-2. Both the POTAMOGETON and FRESHWATER communities maintain no shoot biomass from December to April. Beginning at this time, however, shoot biomass of both communities rapidly increased. The POTAMOGETON community reaches a peak standing crop of 100 gdm-2-2 by October. A precipitous decline of shoot material followed with complete loss by December.

SAV Community Distribution and Abundance

Determination of monthly shoot biomass for all SAV beds from 1986 through 1996 is summarized in Figure 9. During this period SAV standing stock has increased from lows in 1985 and 1986 to highest levels during 1991-1993. High salinity communities (ZOSTERA) dominate during the winter, spring and summer. Lower salinity communities (RUPPIA, POTAMOGETON, and FRESHWATER) are dominant in the fall. At peak biomass in July, total standing stock was nearly 17,800 metric tons in 1996. Minimum standing stock in December and January was about 5,000 metric tons.

Year-to-year comparisons of annual bay-wide maximum community aboveground biomass levels from 1985 to 1996 (Fig. 10) indicate that recovery of SAV in the Chesapeake Bay has occurred principally in the ZOSTERA community. Rapid growth of ZOSTERA beds occurred between 1985 and 1991 with peak biomass increasing from 9,200 to 17,800 metric tons. Nearly constant biomass levels of ZOSTERA have been observed since then. Biomass of FRESHWATER SAV beds have also demonstrated some increases while both RUPPIA and POTAMOGETON beds have fluctuated at nearly constant levels since 1985.

Figure 11a-d. presents detailed year-to-year comparisons of annual peak aboveground biomass of total bay SAV beds within each of the four community types compared to total bed areas as determined by the aerial mapping. As expected, trends over time in both measures of SAV abundance parallel each other. However there are several differences in year-to-year change between biomass and area which suggest the patterns of recruitment or loss of bay SAV communities. For example, a marked decline in total FRESHWATER SAV area between 1986 and 1987 (Fig. 11a) was not reflected in a concomitant change in biomass. This suggests that loss of FRESHWATER beds during this period occurred in sparse beds rather than more densely vegetated areas. Conversely, a rapid increase in FRESHWATER biomass in 1993 and subsequent loss in 1994 which was not reflected in area change suggests that overall during this period many existing beds increased and decreased in biomass but there was little net recruitment into new areas.

Yearly comparisons of total bay SAV biomass and area (Fig. 12) reveal several interesting patterns. The increase in bay biomass was nearly linear between 1985 and 1991, and during the period of 1985 to 1987 biomass increases preceded the bay wide expansion of SAV into new areas. However the decline in SAV between 1993 and 1995 and subsequent slight recovery in 1996 appeared similar in both area and biomass measures. These changes reflected changes occurring in several different SAV communities. From 1993 to 1994 FRESHWATER, RUPPIA and ZOSTERA communities all declined although there was a marked increase in POTAMOGETON beds during this period (Fig. 11a-d). By 1995 the ZOSTERA decline had reversed while the declines in all three lower salinity communities continued. While the ZOSTERA community remained stable in 1996 both the FRESHWATER and RUPPIA beds rebounded. Continued slight decline of POTAMOGETON during this period may have been related to the resurgence of RUPPIA in many of the mid-bay areas.

CONCLUSIONS

The yearly aerial photography and mapping of Chesapeake Bay SAV combined with the now quite extensive ground survey database provides a powerful tool for measuring the response of the bay SAV to environmental change. It can be used to compare the response of similar SAV communities types in different tributaries to bay clean up efforts. This SAV biomass information, which is available through the Internet, will prove to be increasingly useful in community-specific management and restoration. One of the objectives of this study has already been accomplished by providing the data for the calibration and validation of the enhanced Bay Eutrophication Model developed by the US Corps of Engineers, Waterways experiment station.

This project now provides a mechanism whereby SAV ground survey information, whether obtained from scientific agencies, academic institutions or citizen volunteers, will be integrated into the measurement of bay SAV response. However, some areas of the bay tend to be surveyed more intensively than others. Figure 13 presents a summary of the density of SAV ground survey efforts in 1996. As might be expected efforts are currently concentrated in the James River, upper Potomac River and the upper bay, where population centers are largest and volunteer organizations or scientific and management agencies are located. More efforts need to be focused along the eastern shore, especially in the mid-bay region where SAV community diversity is high, and knowledge of year-to-year changes in community composition can lead to further insights into bay SAV response to changing environmental conditions. In addition, one SAV species, Zannichellia palustris, which occurs in many mesohaline areas early in the spring was found to be under-represented in the aerial mapping program. Specific studies should be initiated to determine this species abundance.

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TABLES

TABLE 1. Sources used in development of SAV biomass models for each community type.

- FRESHWATER Community
    - Naylor and Kazyak, 1995
    - Rybicki and Carter, 1995
    - Carter et al., 1994
    - Carter and Rybicki, 1994
    - Carter and Rybicki, 1994 (unpublished)
    - Stevenson et al., 1993
    - Rybicki, 1990 (unpublished)
    - Kilgore et al., 1989
    - Rybicki et al., 1988
    - Rybicki et al., 1986
    - Staver, 1986
    - Staver, 1986 (unpublished)
    - Nichols et al., 1979
- POTAMOGETON Community
    - Stevenson et al., 1993
    - Lubbers et al., 1990
    - Nichols et al., 1979
- RUPPIA Community
    - Moore et al., 1995
    - Stevenson et al., 1993
    - Orth and Moore, 1986
    - Orth and Moore, 1981
- ZOSTERA Community
    - Moore et al., 1995
    - Orth and Moore, 1986
    - Orth and Moore, 1981

TABLE 2. A matrix display of the number of observations out of 10,023 total bay wide observations from 1986-1996 reporting each pair of species.

	Zp	Zm	Va	Rm	Ppu	Ppf	Ppc	Pcr	Nm	Ngu	Ngr	N	Ms	Hv	Hd	Ec	Cd
Cd	54	0	532	3	23	13	40	74	155	117	43	80	981	839	371	172	88
Ec	44	0	143	25	18	62	29	60	44	44	31	11	196	40	7	41	
Hd	5	0	409	1	2	10	8	6	37	58	1	41	622	551	16		
Hv	22	0	877	0	13	3	16	25	298	118	31	66	1453	445			
Ms	54	0	1201	36	8	87	67	32	177	98	17	61	773				
N	6	0	61	4	4	2	5	5	1	6	1	16					
Ngr	17	0	13	0	6	0	0	17	26	19	8						
Ngu	18	0	90	0	14	3	5	22	51	7							
Nm	14	0	135	0	9	0	5	25	4								
Pcr	26	0	40	1	19	5	9	7									
Ppc	51	1	77	53	2	57	79										
Ppf	49	0	70	123	1	89											
Ppu	18	0	13	0	0												
Rm	134	699	25	2387													
Va	34	0	209														
Zm	11	567															
Zp	874																

TABLE 3. A matrix display of Dice's Index of Similarity between pairs of species.

	Zp	Zm	Va	Rm	Ppu	Ppf	Ppc	Pcr	Nm	Ngu	Ngr	N	Ms	Hv	Hd	Ec	Cd
Cd	0.04	0.00	0.29	0.00	0.03	0.02	0.05	0.09	0.16	0.14	0.06	0.10	0.36	0.37	0.30	0.17	1.00
Ec	0.05	0.00	0.12	0.01	0.08	0.15	0.08	0.20	0.11	0.14	0.12	0.04	0.10	0.03	0.01	1.00	
Hd	0.01	0.00	0.28	0.00	0.01	0.02	0.02	0.01	0.07	0.12	0.00	0.09	0.28	0.31	1.00		
Hv	0.01	0.00	0.35	0.00	0.01	0.00	0.01	0.02	0.20	0.09	0.03	0.05	0.42	1.00			
Ms	0.03	0.00	0.39	0.01	0.01	0.05	0.04	0.02	0.10	0.06	0.01	0.04	1.00				
N	0.01	0.00	0.06	0.00	0.05	0.01	0.03	0.04	0.00	0.04	0.01	1.00					
Ngr	0.03	0.00	0.01	0.00	0.10	0.00	0.00	0.16	0.12	0.14	1.00						
Ngu	0.03	0.00	0.09	0.00	0.12	0.01	0.02	0.14	0.18	1.00							
Nm	0.02	0.00	0.12	0.00	0.05	0.00	0.02	0.10	1.00								
Pcr	0.04	0.00	0.04	0.00	0.21	0.02	0.04	1.00									
Ppc	0.07	0.00	0.07	0.03	0.01	0.16	1.00										
Ppf	0.06	0.00	0.06	0.06	0.01	1.00											
Ppu	0.03	0.00	0.01	0.00	1.00												
Rm	0.06	0.26	0.01	1.00													
Va	0.02	0.00	1.00														
Zm	0.01	1.00															
Zp	1.00																

TABLE 4. SAV Community Species Associations.

ZOSTERA Community	*Zostera marina* *
	Ruppia maritima
RUPPIA Community	*Ruppia maritima* *
	Potamogeton perfoliatus
	Potamogeton pectinatus
	Zannichellia palustris
POTAMOGETON Community	*Potamogeton pectinatus* *
	Potamogeton perfoliatus *
	Elodea canadensis
	Potamogeton crispus
FRESHWATER Community	*Myriophyllum spicatum* *
	Hydrilla verticillata *
	Vallisneria americana *
	Ceratophyllum demersum
	Heteranthera dubia
	Najas minor
	Elodea canadensis
	Najas minor
	Elodea canadensis
	Najas guadalupensis
	Najas sp.
	Potamogeton crispus
	Najas gracillima
	Potamogeton pusillus

* Dominant Species

FIGURES

FIGURE 1. Analysis of similarity of SAV species reported in ground truth observations compared to the over water distance between the observations. Chesapeake Bay Program Segment CB6.

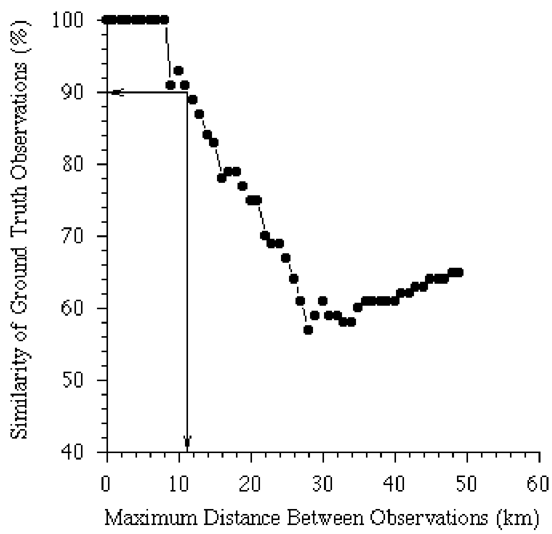


FIGURE 2 Crown density scale used for estimating density of SAV beds from aerial photography.

Rows of squares with black and white patterns represent three different arrangements of vegetated cover for given percentage (Adapted from Paine, 1981).

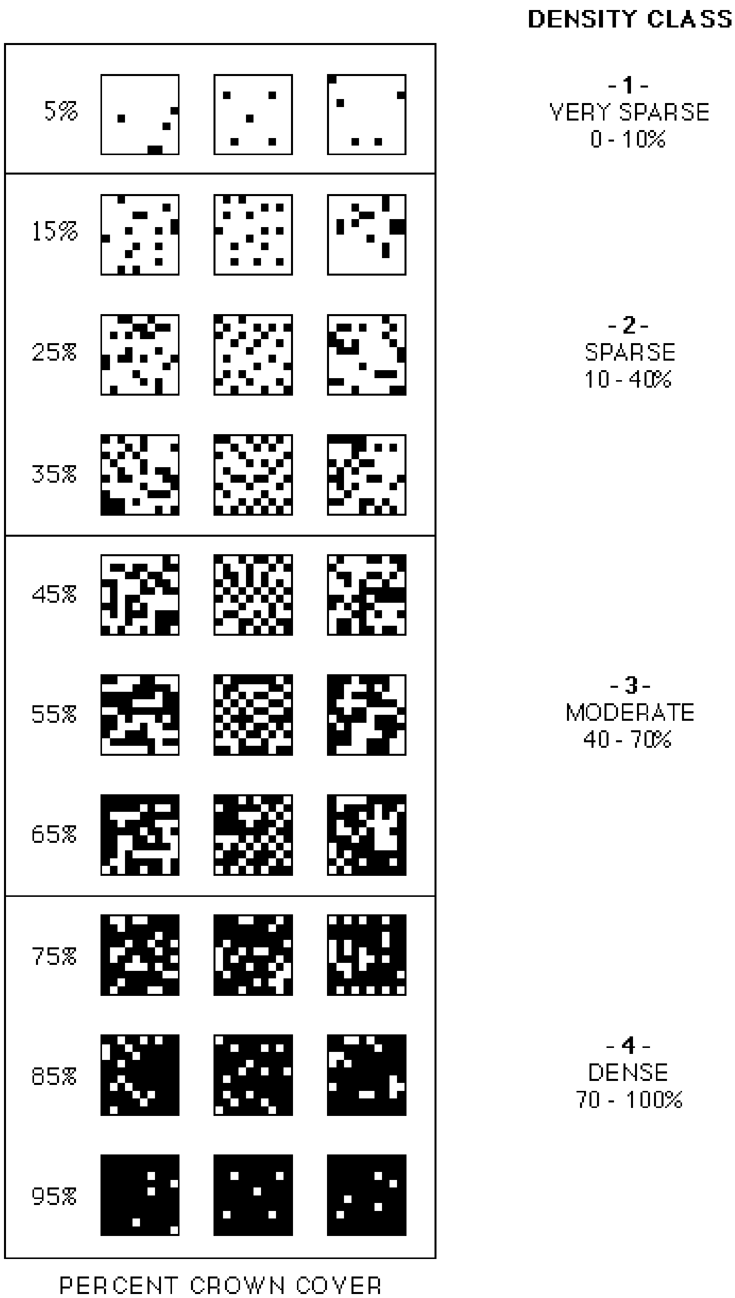


FIGURE 3. Locations of intensive ground truth transects.

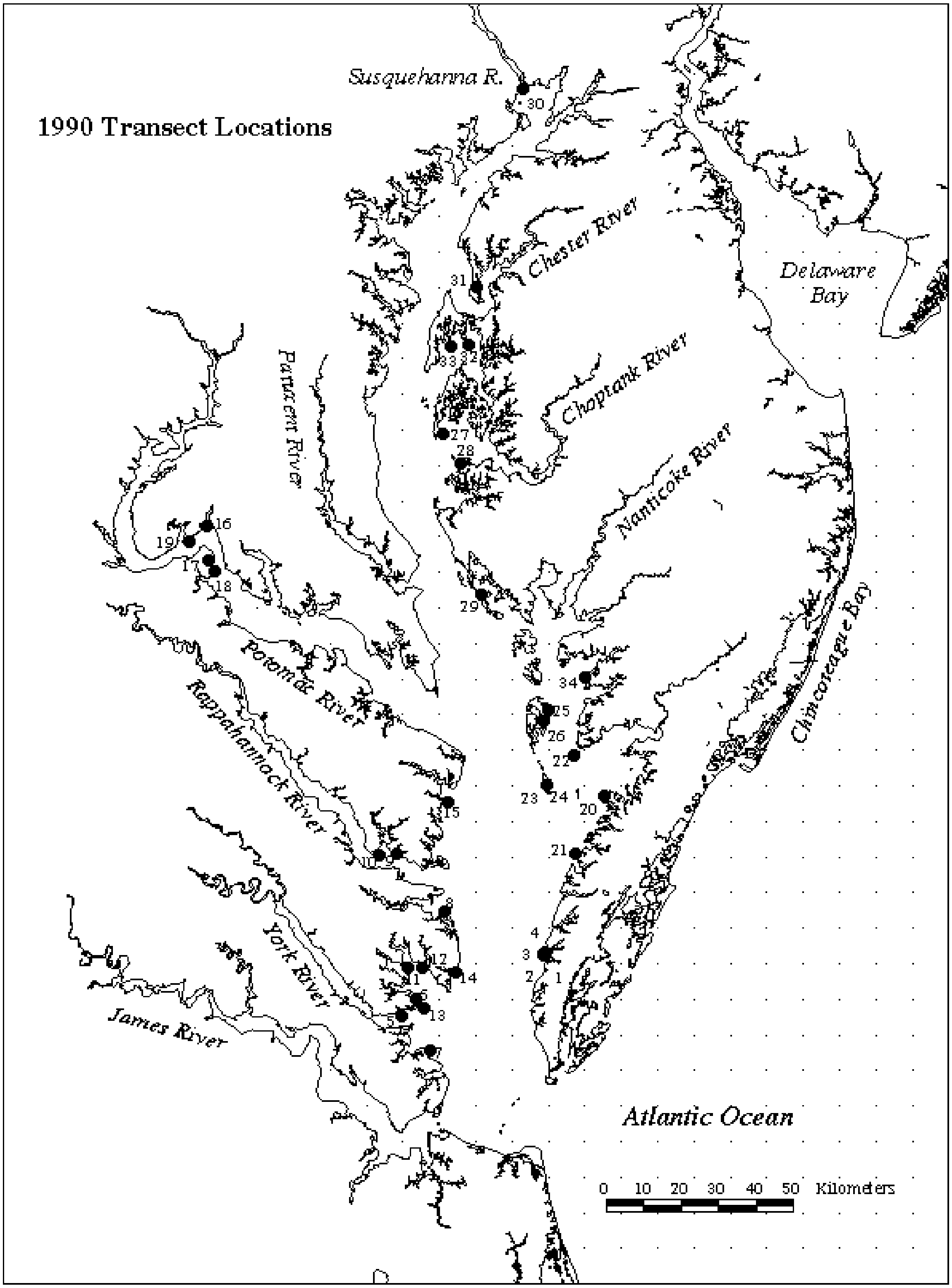


FIGURE 4. Dendrogram of species associations based upon all 1985-1996 ground survey information.

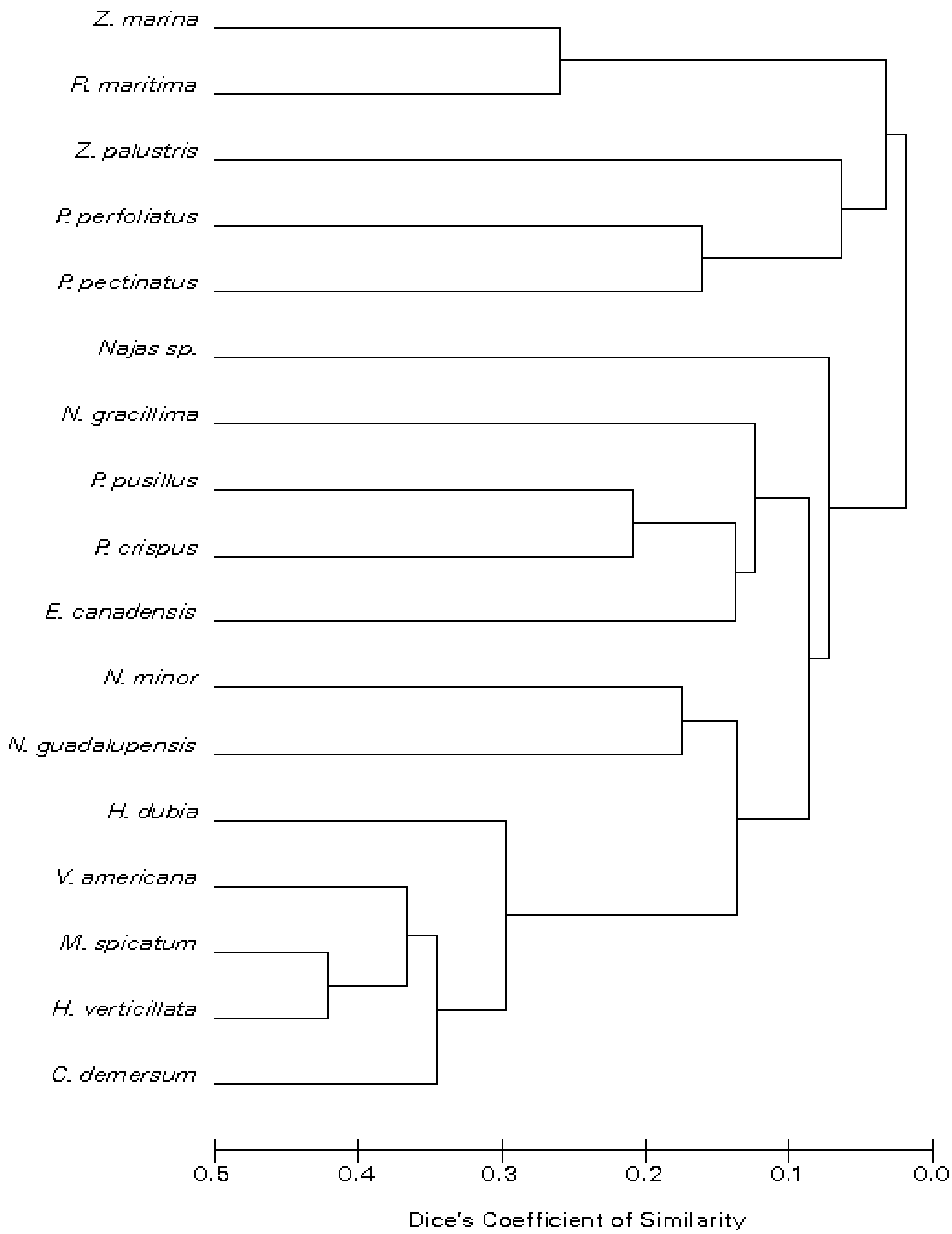
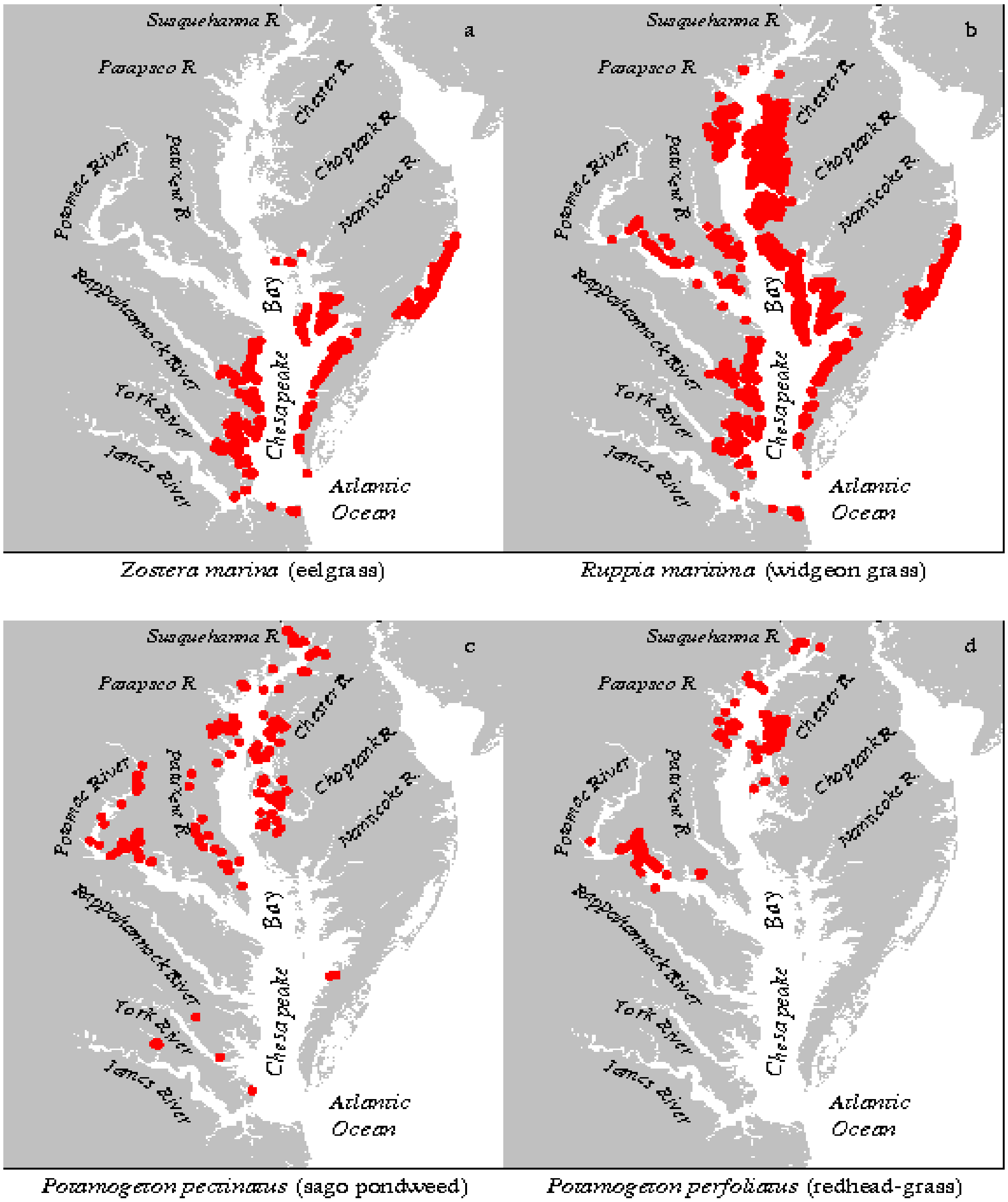
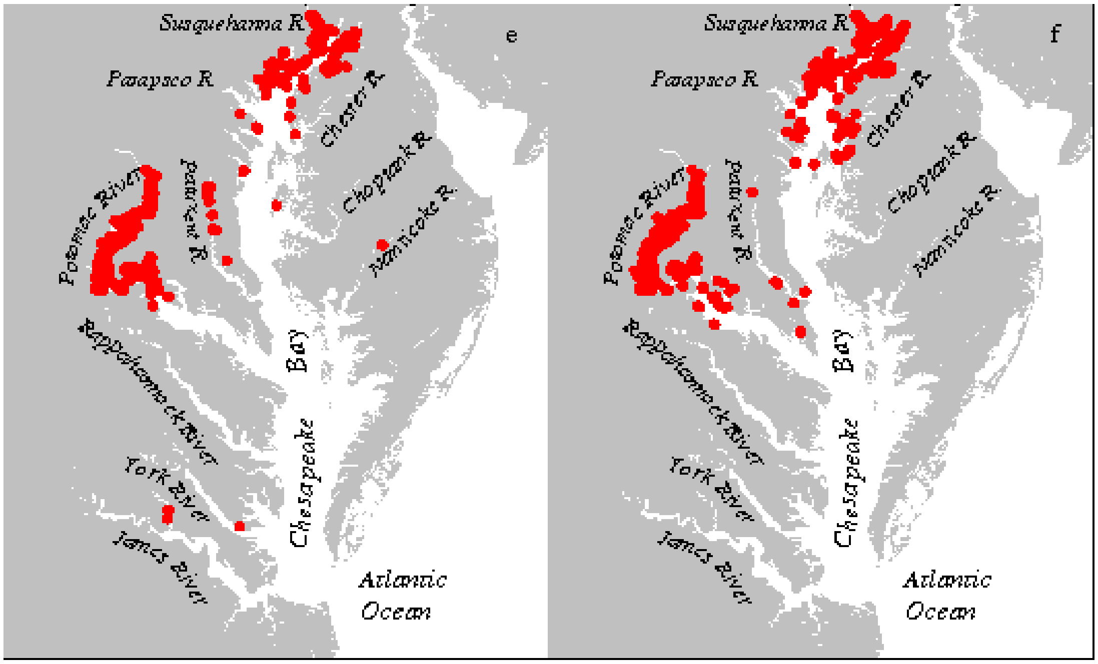
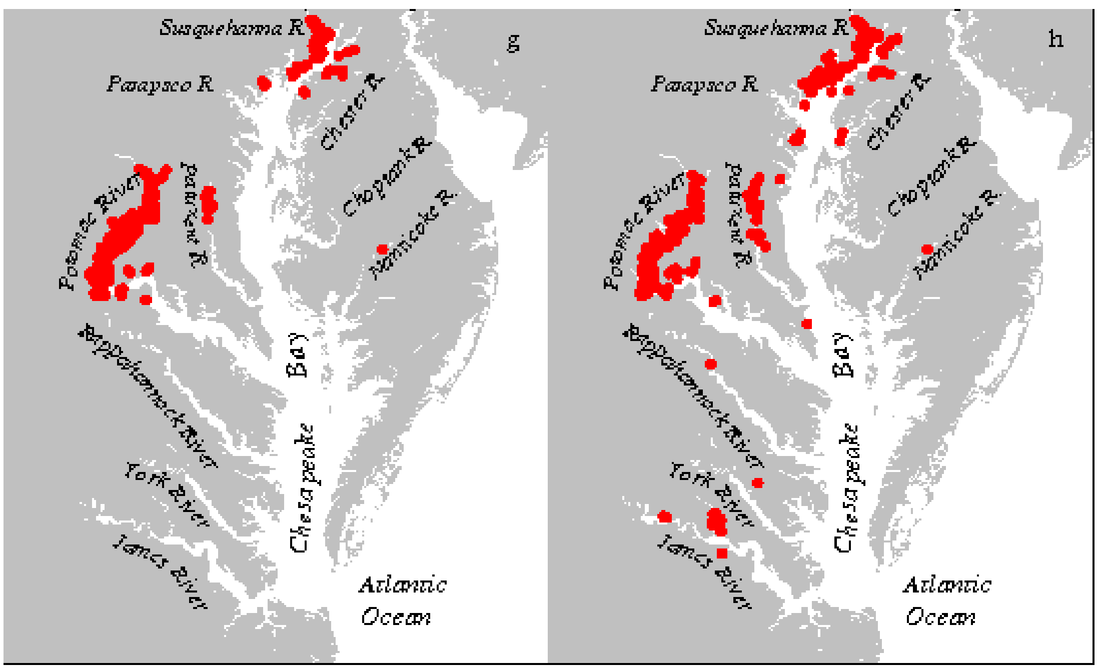


FIGURE 5. a-n. Ground survey observations of individual SAV species, 1985-1996.

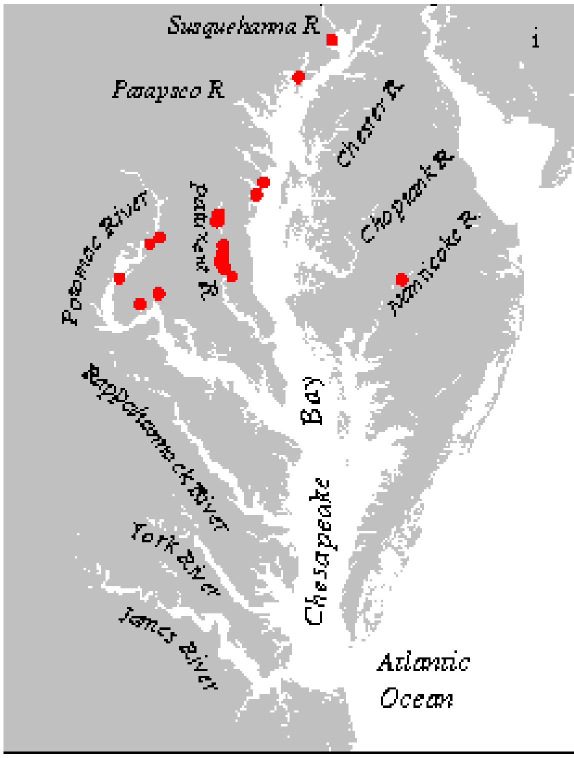




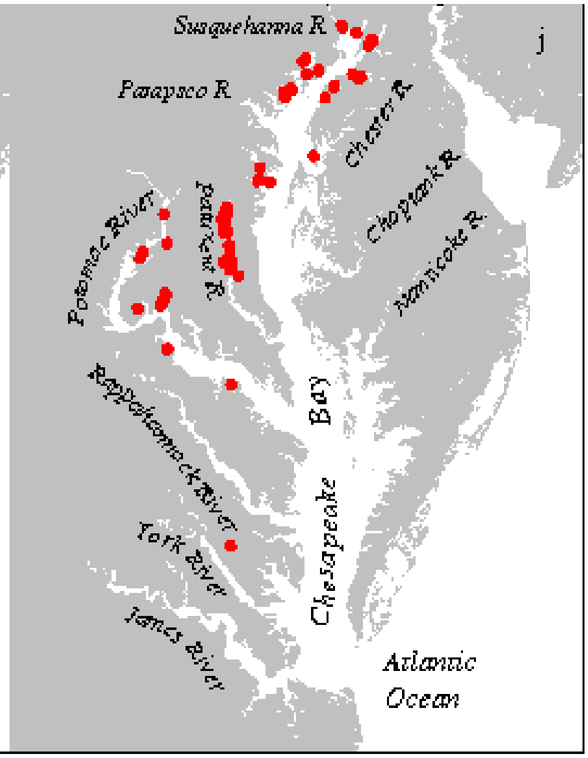
Vallisneria americana (wild celery) *Myriophyllum spicatum* (Eurasian watermilfoil)



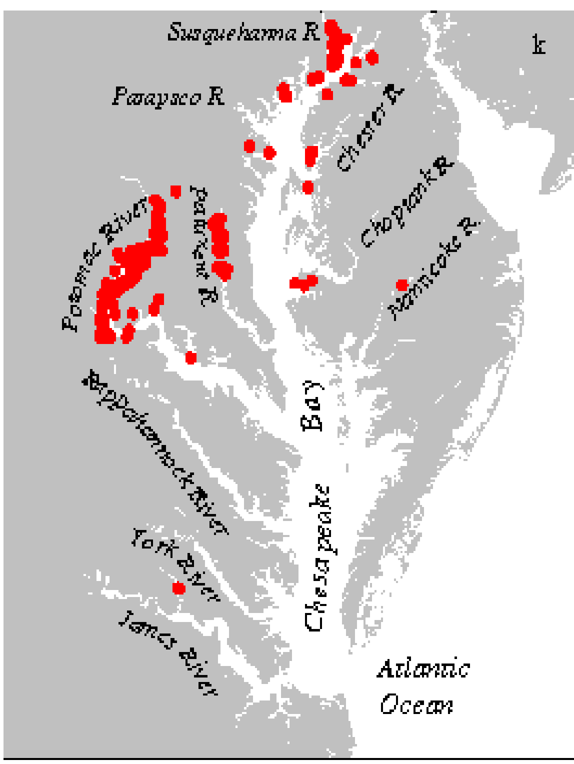
Hydrilla verticillata (hydrilla) *Ceratophyllum demersum* (coontail)



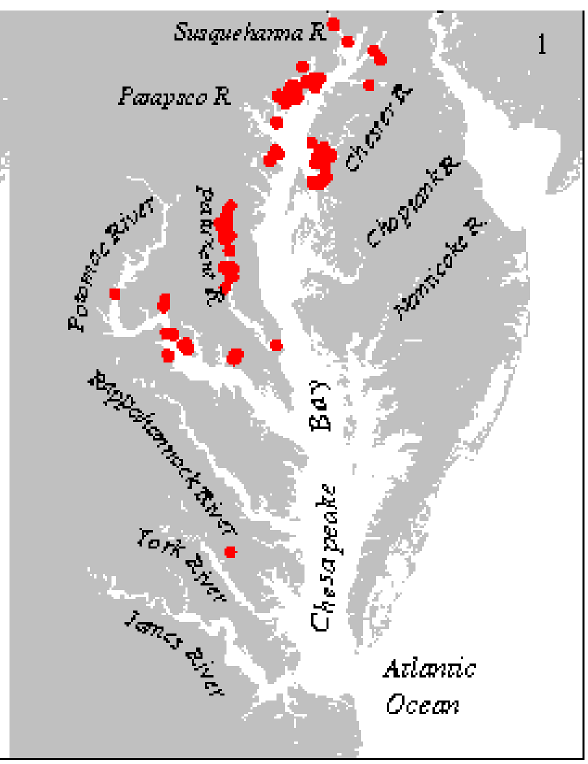
Potamogeton pusillus (slender pondweed)



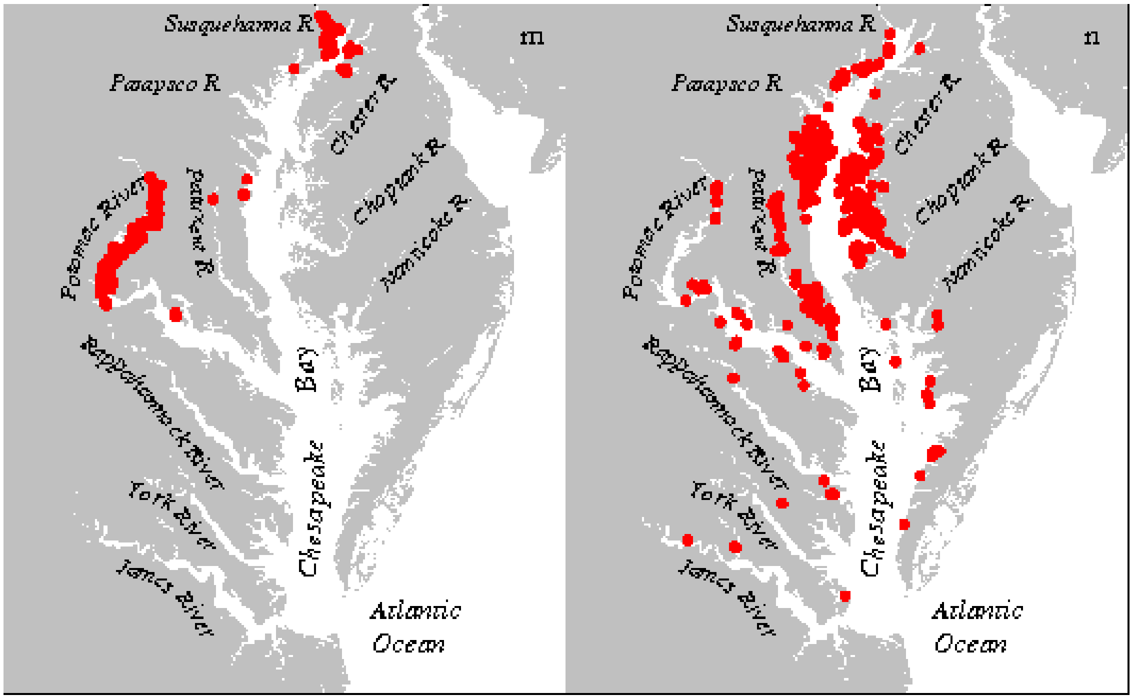
Potamogeton crispus (curly pondweed)



Najas sp



Elodea canadensis (common elodea)



Heteranthera dubia (water-weed) *Zannichellia palustris* (horned pondweed)

FIGURE 6. a-d. Ground survey observations of SAV species by community type, 1985-1996.

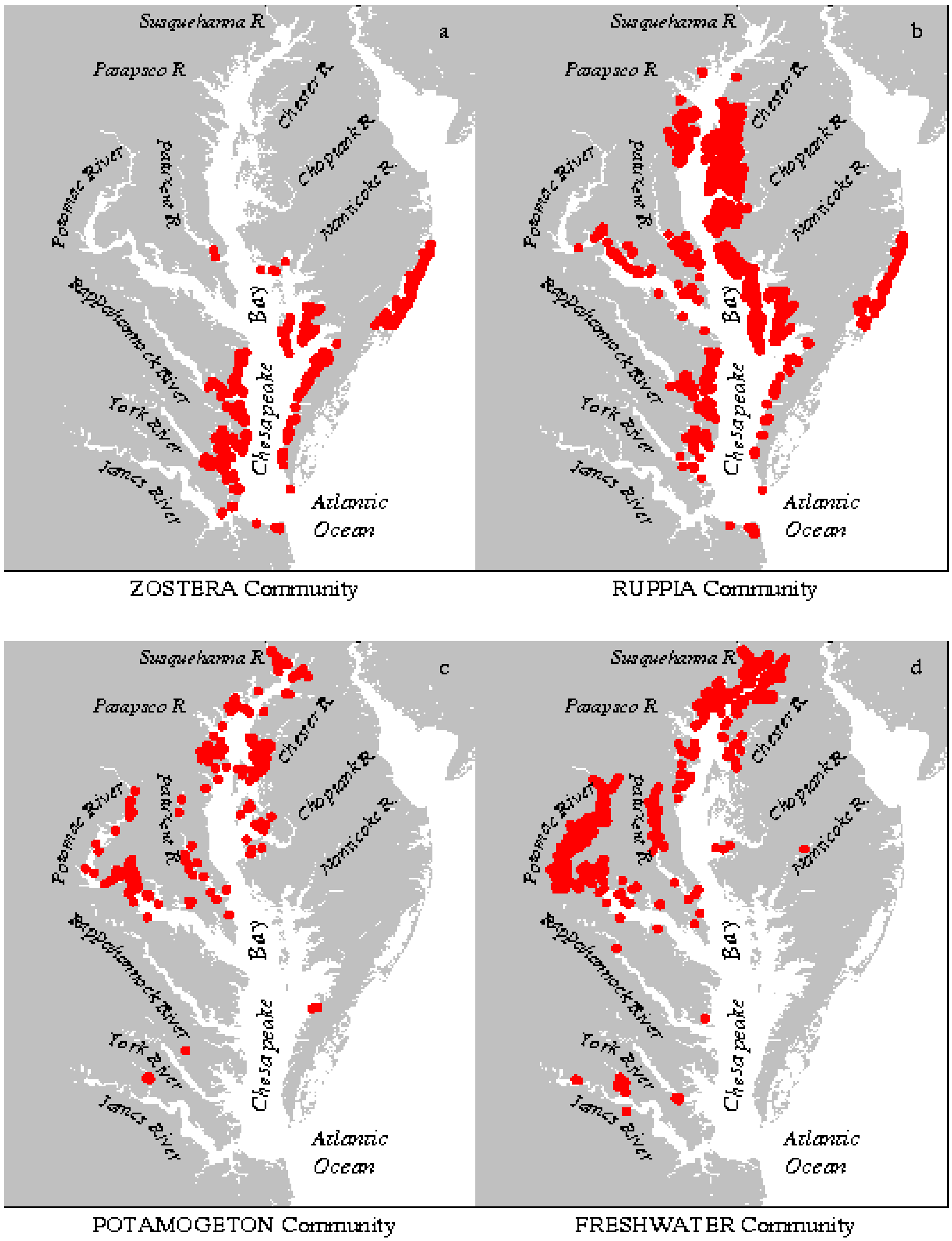


FIGURE 7. Comparison of SAV aerial density classification categories to SAV ground cover measurements.

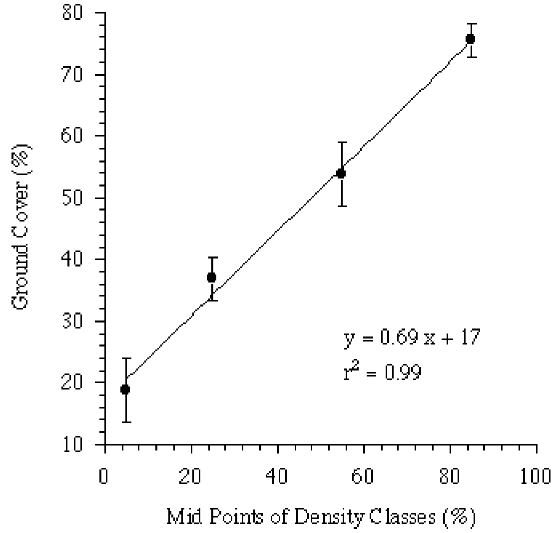


FIGURE 8. Mean monthly (±SE) SAV aboveground biomass by community type.

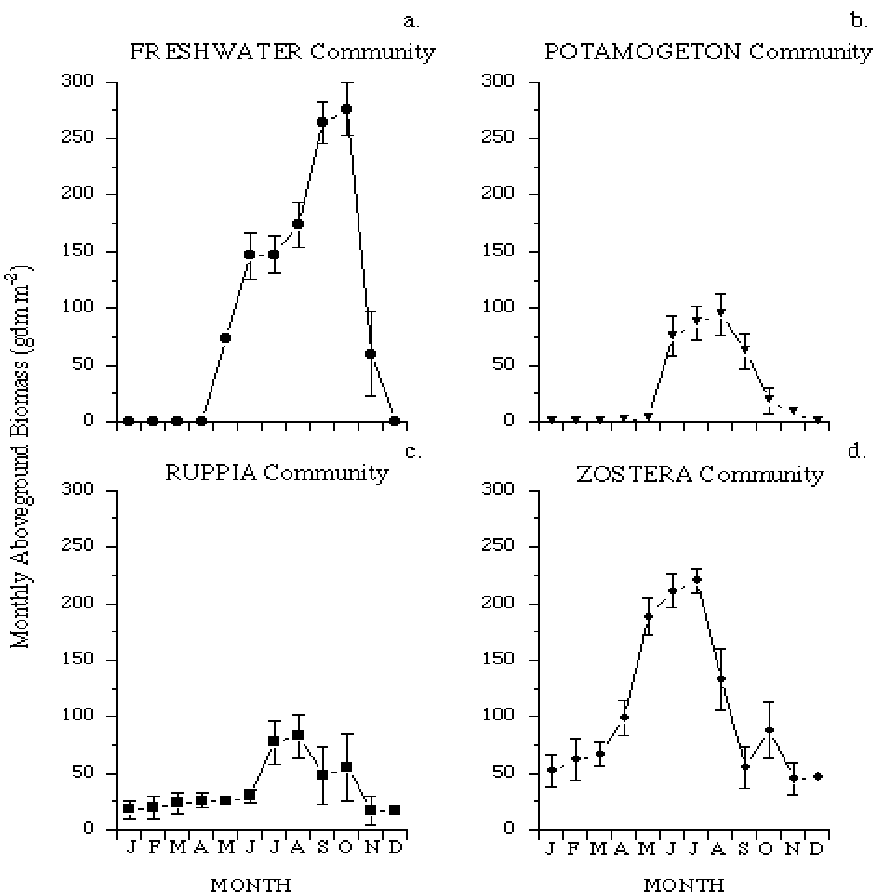


FIGURE 9. Total monthly Chesapeake Bay SAV biomass, 1985-1996.

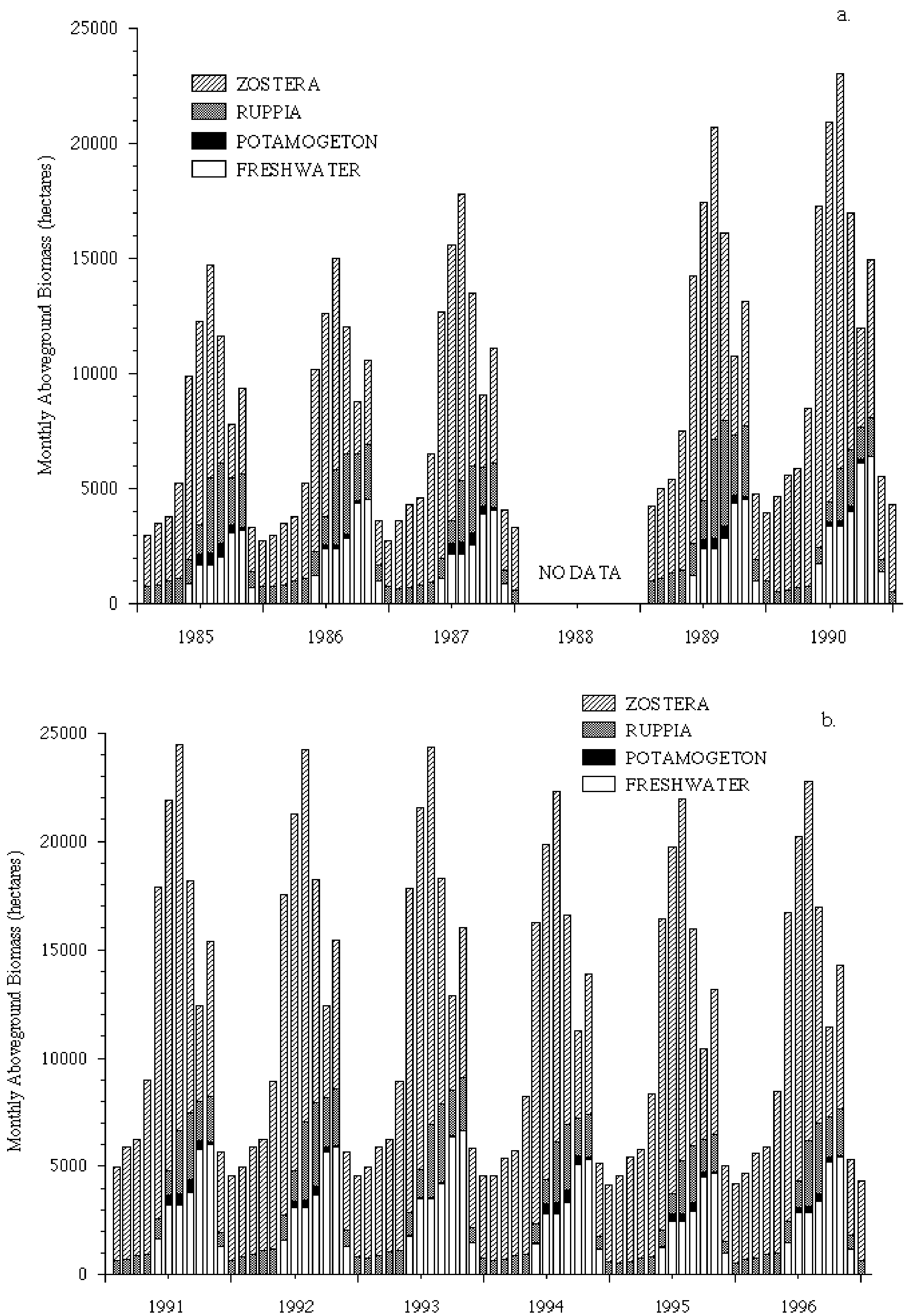


FIGURE 10. Annual peak aboveground biomass by SAV community type.

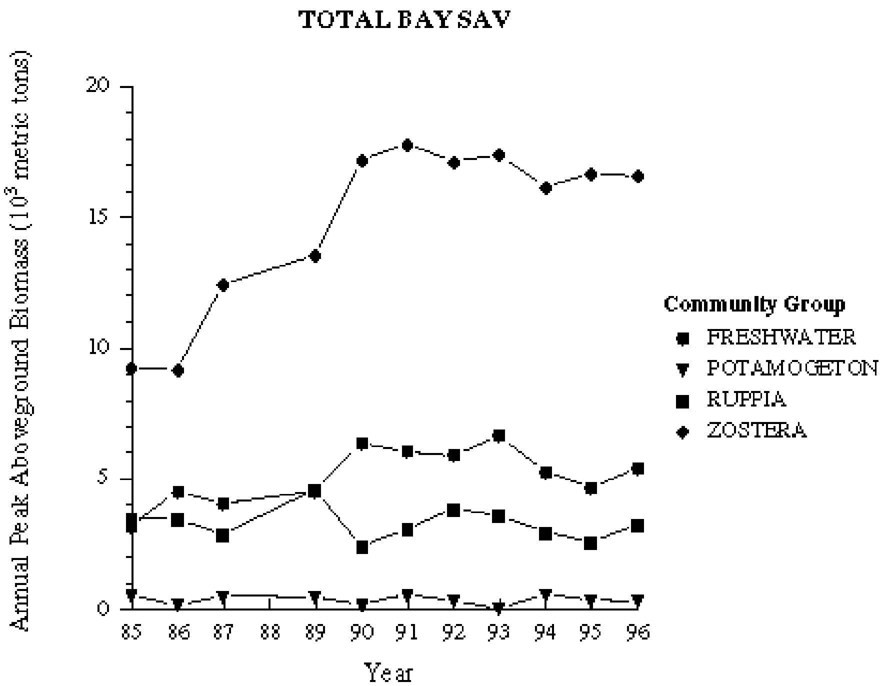


FIGURE 11. a-d. Comparison of annual peak SAV aboveground biomass and area by SAV community type.

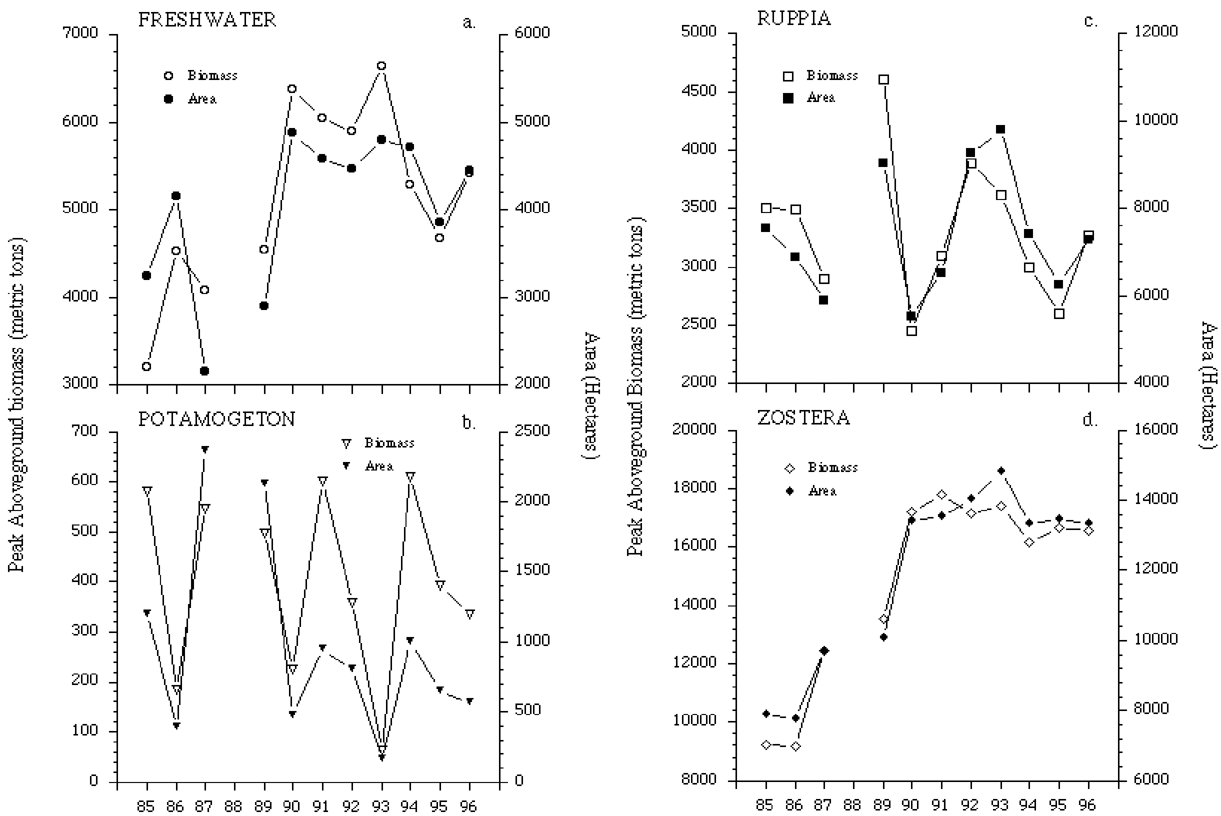


Figure 12. Comparison of total Chesapeake Bay annual peak SAV aboveground biomass and area by SAV community type.

FIGURE 13. Percentage of Chesapeake Bay SAV beds in each of the Chesapeake Bay Program segments which were covered by ground surveys in 1996.