National Park Service
U.S. Department of the Interior

Northeast Region
Philadelphia, Pennsylvania

Evaluation of the Health of Eelgrass (*Zostera marina* L.) Beds Within the Maryland Coastal Bays

Technical Report NPS/NER/NRTR—2007/014

ON THE COVER

SCUBA diver monitoring eel grass bed health. Photograph courtesy of the authors.

Evaluation of the Health of Eelgrass (*Zostera marina* L.) Beds Within the Maryland Coastal Bays,

Technical Report NPS/NER/NRTR—2007/014

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March 2007

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This report was accomplished under Cooperative Agreement 1443CA4520-99-007, Modification #1, with assistance from the NPS. The statements, findings, conclusions, recommendations, and data in this report are solely those of the author(s), and do not necessarily reflect the views of the U.S. Department of the Interior, National Park Service.

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Please cite this publication as:

Harris, L., S. Granger, and S. Nixon. 2007. Evaluation of the Health of Eelgrass (*Zostera marina* L.) Beds Within the Maryland Coastal Bays, Technical Report NPS/NER/NRR—2007/014. National Park Service. Philadelphia, Pennsylvania.

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Acknowledgments

This research was funded by the North Atlantic Coast Cooperative Ecosystem Studies Unit (NAC/CESU). Field logistics and laboratory facilities were supported by the Assateague Island National Seashore group. In particular, Alex Almario, Brian Sturgis, and Chris Lea from the National Park Service provided needed background information, field equipment, transportation, and boat time for the field portion of the research and laboratory facilities for processing samples after collection. In addition, many state agencies in Maryland and Virginia provided background data during the early stages of the research. We would like to thank Margaret McGinty and Cathy Wazniak from Maryland Department of Natural Resources (MDNR) for access to a wealth of monitoring data collected by MDNR. Long-term fish catch data were provided by Steve Doctor, Fisheries Department, MDNR. Finally, we would like to thank Elizabeth Boyer for more information than one can comfortably assimilate about poultry farms in the watershed of Chincoteague Bay.

INTRODUCTION

Unlike many shallow areas along the U.S. East coast that have experienced a decline of seagrass habitat in recent decades, yearly overflights of Chicoteague Bay (MD/VA) conducted by the Virginia Institute of Marine Science have documented an impressive colonization and expansion of *Zostera marina* habitat since the late 1980's. The area covered by submerged aquatic vegetation (SAV) in this system more than tripled between 1987 and 2001 (Fig 1). However, despite the overall positive trend observed in seagrass coverage within Chincoteague Bay, anecdotal reports from commercial fishermen and field observations taken during routine water quality monitoring by National Park Service scientists indicate that some beds in the central region of Chincoteague Bay have experienced losses. Field observations indicated that impacted beds display large patches with a complete loss of plants, and large numbers of dead rhizomes in the sediment.

In addition, there are growing concerns that water quality in the northern Maryland/Virginia Coastal Bays complex has been declining in recent years and that nuisance macroalgae are growing more widespread and persistent. An increase in nutrient inputs as a result of development pressure in and around Ocean City, Maryland has been identified as a possible contributing factor. As a consequence of these conflicting reports concerning seagrass health (overall health vs local die-back) and water quality in Chincoteague Bay, we field-tested a number of seagrass growth parameters that might be interpreted as metrics of eelgrass health and of anthropogenic nitrogen enrichment at several locations in the Maryland Coastal Bays during the summer of 2001

Background

Our laboratory has been examining the impacts of anthropogenic nutrient inputs to shallow coastal areas for many years, often using an experimental lagoon mesocosm facility to examine the sometimes confusing relationship between nitrogen enrichment and its effect on eelgrass growth and vitality (Fig. 2). The Maryland Coastal Bays were an ideal field setting within which to test some of the hypotheses and metrics of seagrass health developed from mesocosm experiments. One reason that nitrogen input-eelgrass health relationships remain unclear is that the major diagnostic assessment tool for eelgrass has been very crude – area coverage of beds (e.g. Short et al. 1996), often based on photo imagery from aircraft. While such a metric can be useful in areas with very dramatic loss of beds, it does not provide information that would indicate chronic stress or be helpful in alerting managers to the incipient loss of beds. We have examined the effects of nutrient enrichment in controlled and replicated experiments using the shallow, high salinity, 4 m^3 mesocosms located at the University of Rhode Island Graduate School of Oceanography (e.g Taylor et al. 1995, Bintz et al. 2003). Several of these experiments were designed to assess ecological parameters that might be useful as indicators of nutrient enrichment in shallow systems.

Our experience with over a decade of shallow water mesocosm experiments has suggested that a modest set of plant growth parameters can be a reliable indicator of eelgrass vitality and persistence. These include shoot density, and the relative rates of production of rhizomes, leaves, and lateral shoots. Examples of these results are shown in Tables 1 and 2. Shoot density declined under nutrient enriched mesocosm conditions as shown in Table 1. The number of days between new leaf initiation (the plastochrone interval) increased under experimental conditions of warmer water temperatures, with even longer intervals seen under conditions of enrichment and increased temperature (Table 2, Bintz et al. 2003). When a relationship correlating surviving plant numbers with the mean plastochrone interval is constructed from these experiments, it is clear that a decline in shoot density is related to slower leaf growth (Figure 1). These are two of the potential indicators that were tested at various locations in the Coastal Bays.
We also took the opportunity to investigate recent work by McClelland et al. (1997) where they noted the lack of sensitive warning indicators of *Zostera* demise and suggested that the ratio of the heavy isotope of nitrogen (^{15}N) to the much more common lighter isotope (^{14}N) in plant leaves might be a useful tool to indicate anthropogenic N impacts. A strong relationship was also reported between the nitrogen ratios (usually referred to as $\delta^{15}N$ or delta ^{15}N) of macroalgae and the extent of urbanization adjacent to coastal waters. McClelland et al.'s (1997) work has stimulated considerable interest in the management community as well as among researchers. This report details our attempt to intercompare these indicators and correlate them with riverine nutrient inputs

as a test of their usefulness as early warning tools. Consequently our first efforts focused on identifying sampling stations in Chincoteague Bay located near ongoing monitoring sites and with seagrass beds that would reflect the effects (stress) of a wide range of environmental conditions.

STUDY LOCATIONS AND METHODS

Five sampling sites along a longitudinal axis through the Maryland Coastal Bay system were used to measure eelgrass production indicators (Fig. 3). These locations were chosen because of the perceived north-south gradient of poor to high water quality from the developed areas around Ocean City to the rural, agriculture dominated land use in the Virginian portion of Chincoteague Bay. Field sites were chosen in Sinepuxent and Spence Cove located near NPS water quality monitoring sites (NPS stations 2 and 3) with water depths of 1 m and 0.5 m, respectively, and with a tidal range of approximately 0.5 m. These locations were considered "impacted" by Park Service scientists. Reports of seagrass die-off at the Tingles Island seagrass meadows caused by the accumulation of macroalgal mats over the bed also indicated that this site may display characteristics of an impacted site. This tagging site is closest to NPS water quality monitoring station 16. The southern sites were located at NPS water quality station 8 near Coards Marsh and a shallow site in Horntown Bay. NPS water quality monitoring station 10 is closest to the Horntown Bay eelgrass tagging site. Both of these eelgrass tagging sites have demonstrated a recent expansion in seagrass habitat and represent the most pristine sites in our surveys.

Stable Isotope Ratio of Riverine Inputs

An indication of anthropogenic nitrogen enrichment can be seen in the ratio of N^{15} atoms to N^{14} atoms in either dissolved inorganic forms of nitrogen in water (nitrate and ammonia) or organic form in plant tissue. As a general rule, dissolved nitrogen brought into an estuary from offshore displays a low ratio (eg 2.0) while the dissolved nitrogen from the Assateague sewage treatment plants displayed a high ratio (>30.0). Whole water samples were collected from several small streams entering Chincoteague Bay and placed in 500 ml amber polyethylene bottles. The samples were acidified by adding 4 ml of 2N sulfuric acid to stop biological action and stabilize the sample for transport to our laboratory in Rhode Island. Water samples were sent to the Boston University Stable Isotope Laboratory (http://www.bu.edu/sil/) for determination of the inorganic forms (NH_4 and NO_3) of nitrogen and δ^{15} N within one week of their collection.

Eelgrass Measurements

Density: The number of eelgrass plants per unit area is an indicator of the vitality of a seagrass bed because it integrates both individual plant survival and prior lateral shoot production. We view density as a relatively long-term (weeks-months) indicator of previous conditions. Geographic Information System (GIS) was used to locate the boundary of each seagrass bed located near each sampling site. Boundaries taken from 1999 overflight data (http://www.vims.edu/bio/sav/index.html) were entered into our base map and a random number generator provided geographic coordinates of 50 locations within each bed. We used differential GPS to guide us to the sample locations in the field where density measurements were made by collecting an intact core (box corer 0.25m X 0.25m) and rinsing the retrieved plants free of sediment. Individual shoot counts were completed after returning to the NPS Field Station. In a number of cases the predetermined sampling coordinates were located in water too shallow for our pontoon boat, as a consequence we sampled as many of the locations as we could reach or as time would allow.

Eelgrass Production: We measured the rate of production of *Zostera* rhizomes, leaves, and lateral shoots using a rhizome tagging technique modified from Bulthuis and Woelkerling (1983) and Dennison et al. (1987). Initial tagging took place over three days between May 1-3. Three plots were marked at each site with four 2.5 cm PVC pipes placed in the sediment and positioned with differential GPS. Within each of these plots, 9 plants were tagged for production measurements for a total of 27 plants. A 3-inch cable tie was placed around the shoot rhizome just below the first root node. The second and third oldest leaves were then stapled to provide additional reference marks for growth measurements. Upon retrieval, the presence of staples on tagged plants ensured that no new leaf material was lost due to sloughing. Figure 4 provides an illustration of this technique. All sites were tagged using SCUBA and the assistance of a NPS vessel and boat operator.

This combination technique provides the necessary information to quantify the plastochrone interval (rate of new leaf initiation, leaves d^{-1}), the rate of production of new lateral shoots, as well as an estimate of new leaf surface area production of leaves (cm^2 d^{-1}) and root/rhizome elongation (cm d^{-1}). After thirty days, we returned to the sites to collect the tagged plants between May 30 and June 2. The new nodes produced in front of the cable tie were counted along with the number of leaves and their length and width. Rhizome nodes represent leaf scars and therefore indicate leaf initiation. The cable tie also allowed us to determine the length (cm) of new rhizome material produced in each plant since it was marked. Estimates of new surface area production were calculated by dividing the average area of the third leaf by the plastochrone interval.

$^{15}N/^{14}N$ Analysis: In addition to tagging, samples of *Zostera* tissue were collected for $^{15}N/^{14}N$ analysis. Portions of new leaf material, preferably the second newest leaf, were rinsed free of salts with deionized water, dried in a forced air oven at 60º C to a constant weight, ground with a mortar and pestel, placed in acid-washed scintillation vials and stored in a dessicator, before being sent to the Boston University Stable Isotope Laboratory (http://www.bu.edu/sil/) for analysis. A few samples of macroalgae found near the tagging plots were also collected and processed in an identical manner as the seagrass for $^{15}N/^{14}N$ analysis.

Sediments: In order to provide some characteristics of the sediments at each tagging site, sediment cores were taken to determine carbon to nitrogen ratios (Fig 7). Six syringe cores (28 mm diameter) were taken at each site and extruded so that the top six centimeters could be retained for analysis. Triplicate pooled samples for each site were produced by mixing two syringe cores together to reduce analytical expense and the inherent variability observed in sediment samples. The pooled sediment samples were placed in separate plastic bags with deionized water to remove salts and transported back to the laboratory where they were placed in aluminum weighing pans and dried in a forced air oven at 60° C until reaching a constant weight. The dried sediment samples were homogenized with a mortar and pestle, then placed in acid-washed scintillation vials and stored in a dessicator until analysis. Particulate forms of carbon and nitrogen were determined using a Carlo-Erba elemental analyzer at the University of Rhode Island.

Aerial Overflight: One of the most challenging aspects of working in a large embayment like the Maryland/Virigina Coastal Bays complex is to select stations and develop a survey scale that is representative of the area. Aerial overflights offer a fairly inexpensive method of assuring that large scale processes were considered in our sampling design. In order to document evidence of seagrass die-off and conditions that existed during our field-work (June 2001), we hired a small aircraft to photographically record the condition of the seagrass beds. The photographs were intended as a general guide to Chincoteague Bay and are not geographically registered. We have, however, provided the approximate location of each photograph and a high resolution image for each location on an accompanying CD.

RESULTS

The plastochrone interval was calculated by taking the number of new nodes produced and dividing by the number of days in the tagging period for each site. Figure 5 reports the mean value for this measurement at each of the five sites, along with the standard deviation. There was very little variability among mean plastochrone intervals at each of the sites. The graph for this information lists the sites from north to south along the x-axis, a convention that will be used for all similar graphs in this section. Because temperature can affect production of *Zostera marina* (Marsh et al. 1986, Olesen and Sand-Jensen 1993), a comparison of these values with results of the Rhode Island Mesocosm experiments necessitates evaluating the time intervals with respect to local temperatures. This was accomplished by using the National Park Service water quality monitoring data from stations 2, 3, 16, 10, and 8 where water temperatures were recorded from the months of May and June. Because the plastochrone interval effectively integrates the environmental conditions experienced by the plant over the time period of tagging, an average value for these two months was calculated for each tagging site. These values are plotted against one another in Figure 6, along with the results of the nutrient and temperature manipulation experiments completed in the Rhode Island mesocosms during 1999 (Bintz et al. 2003). Plastochrone intervals measured at two locations in a Rhode Island Coastal Pond are also reported. It is clear that the plastochrone interval reported from the Rhode Island field location are shorter, representing faster leaf initiation rates. However, plastochrone intervals measured at the Spence, Tingles, and Horntown Bay sites are comparable to those measured in the lagoon mesocosms during June within a warm, nutrient enriched treatment.

It is more difficult to compare the results of the growth measurements with the results from the Rhode Island mesocosm data because the morphology of the plants differs between geographic regions. The maximum leaf lengths of the plants measured in Maryland and Virginia range between 11 and 25 cm, whereas Rhode Island plants in the mesocosms are typically 20 to 60 cm in length. However, we can convert absolute surface area growth to an area-specific growth rate. Figure 7 displays these data from the field sites in and around ASIS along with a graph of specific growth rates measured in the Waquoit Bay estuaries of Massachusetts studied by Hauxwell et al. (2003) and one station in Ninigret Pond, Rhode Island, plotted with respect to watershed nitrogen loads. While the Southern eelgrass appears to exhibit slightly slower specific growth rates, it should be apparent that there appears to be little effect of nitrogen loading on relative growth rates, so this growth parameter on its own may not be an appropriate indicator. Temperatures from the Waquoit Bay measurements are unavailable, so it is unclear if the higher growth rates might be attributable to temperature differences.

Although the leaf growth rates may not indicate differences, we did choose to examine the average longest leaf lengths of tagged plants as a potential indicator of nutrient enrichment. Elongation of leaves has been a recurring hallmark of water column nitrogen enrichment (Touchette and Burkholder 2000, Bintz et al. 2003). While we do not have area-specific nitrogen loading for the various sites measured for this project, we were able to take the water column NH_4 concentrations measured at nearby NPS water quality monitoring stations and plot these values with longest leaf lengths in Figure 8. It does appear that leaf lengths at the Sinepuxent site correspond with higher ambient dissolved nitrogen concentrations. However, there is very little difference between the other stations and the longer leaf lengths at the Sinepuxent site may reflect the deeper water column (1m versus 0.5m or less at other sites).

One other technique of interpreting the tagging results is to consider the relative allocation of plant resources to above versus below ground material. We compared the leaf surface area produced during our initial and final monitoring surveys to the length of new rhizome material. This relative comparison is important because eelgrass morphology can change in response to sediment and hydrodynamic conditions. A ratio eliminated the site-specific morphological characteristics that might cloud this comparative analysis. Figure 9 displays this ratio for the five sites. It is clear that the two northern stations at Spence Cove and at the Sinepuxent marker allocated relatively higher amounts of growth to leaves than to rhizomes. We have observed this response of seagrass to nitrogen enrichment in several of our mesocosm experiments (Bintz et al 2003). There is also a clear relationship between plastochrone interval and rhizome elongation, as shown in Figure 10. Plants that produce leaves faster (shorter Plastochrone Intervals) produced longer rhizomes overall. Because a new internode is produced on the rhizome with each new leaf, this correlation is explained by basic botany. However, it also highlights the importance of measuring production in units of biomass in the future. The mean number of new lateral shoots produced on each plant was highly variable and was not significantly different among sites (Figure 11). However, Tingles Island and Spence Cove had lower mean values than the other three sites. The percentage of plants producing new lateral shoots during the tagging period was comparable to the results of the 1999 mesocosm temperature/enrichment experiments (Bintz et al. 2003). However, the Horntown and Sinepuxent sites exceeded the percentages observed in the experimental conditions.

Lastly, it is important to consider the shoot densities measured at each of these sites. Figure 13 reports these densities in two different ways. Because we collected density cores using pre-determined, random GPS coordinates, there were some areas where we collected many “zero” cores. Mean densities are shown both inclusive of these zero values and after their removal. Again, there were no significant differences between the sites although it appears that densities were slightly higher in the northern stations. There appears to be an inverse relationship between shoot density and lateral shoot production rates (Figure 14), a pattern previously observed in our mesocosm experiments and documented as an example of the “self-thinning” trend of monocultures (Harris et al. *in* *prep*). These values are far above the mesocosm densities used for experiments in Rhode Island (365 shoots m^{-2}).

Figure 15 displays a map of the study location along with the results of the stable isotope analysis. The delta ^{15}N values of the eelgrass samples at the five stations are included with the river measurements to provide a contextual basis of freshwater N inputs. While a high riverine $^{15}N/^{14}N$ ratio indicates that the source of nitrogen enrichment is anthropogenic, it is important to note that the ratio is not a measure of nitrogen flux or load from the river. Oceanic $\delta^{15}N$ are low. Sinepuxent and Horntown Bays reported the highest $\delta^{15}N$ values.

Ratios of carbon to nitrogen for the five sites are shown in Figure 11. Both Tingles Island and Coards Marsh sites had significantly higher values than the other sites (ANOVA $p<0.05$), and the sediments at these sites were also finer than the other three locations.

Although there were few significant differences among the sites, we have provided a summary map in Figure 12 of the relative differences among their locations.

The aerial overflight revealed two significant issues that may affect the longevity of the area eelgrass meadows. In the southern portion of Chincoteague Bay, and in many areas of the central portion, there were significant propeller scars, many in a circular pattern from commercial clamming. We could also see extensive mats of floating algae, possibly *Ectocarpus* that appeared to be wind-driven to the eastern portion of the bays.

DISCUSSION

The surprising result of this study was the similarity among the various sites despite a perceived north-south gradient of poor water quality. Indeed, Horntown Bay results indicated higher $\delta^{15}N$ values, low density, and low production of the eel grass. It should be noted that large mats of floating macroalgae usually develop in June and their impacts may not have been integrated into the growth measurements because of the early period (May) we chose for tagging.

There is also a clear relationship between shoot density, lateral shoot production, and possibly leaf production. In areas with higher density, there were relatively lower numbers of lateral shoots produced over the tagging period. Spence and Sinepuxent sites, with the highest reported mean densities, also had higher above to below ground growth allocation ratios. This may indicate that within the higher density areas, i.e. crowded sites, more energy was devoted to leaves and light capture than to other processes. Because longer leaf lengths were also observed under high dissolved water column nitrogen concentrations, this aboveground allocation may also signify water column shading by phytoplankton or macroalgae blooms.

The comparison of tagging parameters to data collected by our group in Rhode Island was particularly revealing for the plastochrone interval results. Without data describing biomass allocation, this parameter appears to be one of the easiest and fruitful measurements to make. Because the rhizome tagging involved in this process will also reveal lateral shoot production, these may be the most appropriate indicators to use for any future monitoring work. By combining all the tagging results, the stable isotope measurements, and the C:N data, we were able to make a preliminary "grading" of the sites during Steve Granger's presentation at ASIS in 2002. This is indicated by the color coding in Figure 17, with Sinepuxent and Coards Marsh considered in better condition than Tingles, Spence, or the Horntown Bay sites. These same site grades were validated by the comparisons with mesocosm data for the plastochrone intervals and the percentage of lateral shoots produced.

One last test of our evaluation of these locations within the MD/VA Bays complex is to use the SAV distribution maps generated by the Virginia Institute of Marine Science to evaluate how our predictions of eelgrass meadow health fared against the actual coverage of the meadows around each tagging site. Maps of the areas around the sites displaying changes in SAV from 2000, 2001, & 2002 are displayed in Figures 18 – 21. Perhaps the most dramatic decline at these locations was at the Horntown site (Figure 21). There was also a decline in coverage around Tingles Island. Spence Cove did not exhibit a decline, although the VIMS report for 2003 did document a decline in coverage. It is possible that the high density of the eelgrass in this area created a slower rate of decline.

The Coards Marsh site presents an interesting insight that is only possible with such a retrospective evaluation. While the actual location of the tagging site did not exhibit losses, the edges of the large meadows in this region experienced significant declines of

SAV distribution in 2002. The SeagrassNet program (http://www.seagrassnet.org/) advocates measuring the deepest extent of seagrass meadows as part of a sampling protocol designed to provide long-term monitoring of seagrass distribution and health on a global basis. The Coards Marsh decline might have been more readily predicted had we located our tagging site at the marsh edge.

The eelgrass growth values provide NPS with a baseline for future monitoring endeavors should they choose to measure eelgrass growth. At a minimum, it appears that density, plastochone interval, and lateral shoot production should be included in any future measurements. By narrowing the measurement parameters to these three, the tagging procedure can be simplified to include rhizome cable tie tagging only.

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Table 1. Number of eelgrass plants in late August in mesocosms maintained at different temperatures with and without inorganic nitrogen (NO_3) and phosphorus (PO_4) enrichment.

	Number of plants, mean (± SD) [a]
Unenriched	
field temperature	487 (± 49)
field temp + 4°C	218 (±127)
field temp – 4°C	648 (±1)
Enriched [b]	
field temp + 4°C	16 (±26)
field temp – 4°C	444 (±66)

[a] All treatments began in April with 580 plants. Equal numbers of plants were removed for sampling each treatment.

[b] DIN input = 6 mmol N m^{-2} d^{-1}, DIN:DIP ratio =12

Table 2. Mean *Zostera* Plastochrone Interval (days) (± SD), Mesocosm Experiment, 1999

Treatment	June	July	August
Field Temperature	9.4 (0.8)	11.6 (0.6)	11.9 (0.6)
+4°C	11.8 (0.6)	17.4 (5.1)	21.1 (1.1)
+4°C enriched[a]	14.3 (1.1)	22.8 (*)	21.5 (7.8)

[a] DIN input = 6 mmol m^{-2} d^{-1}, DIN:DIP ratio = 12

*All plants died in one of the mesocosms

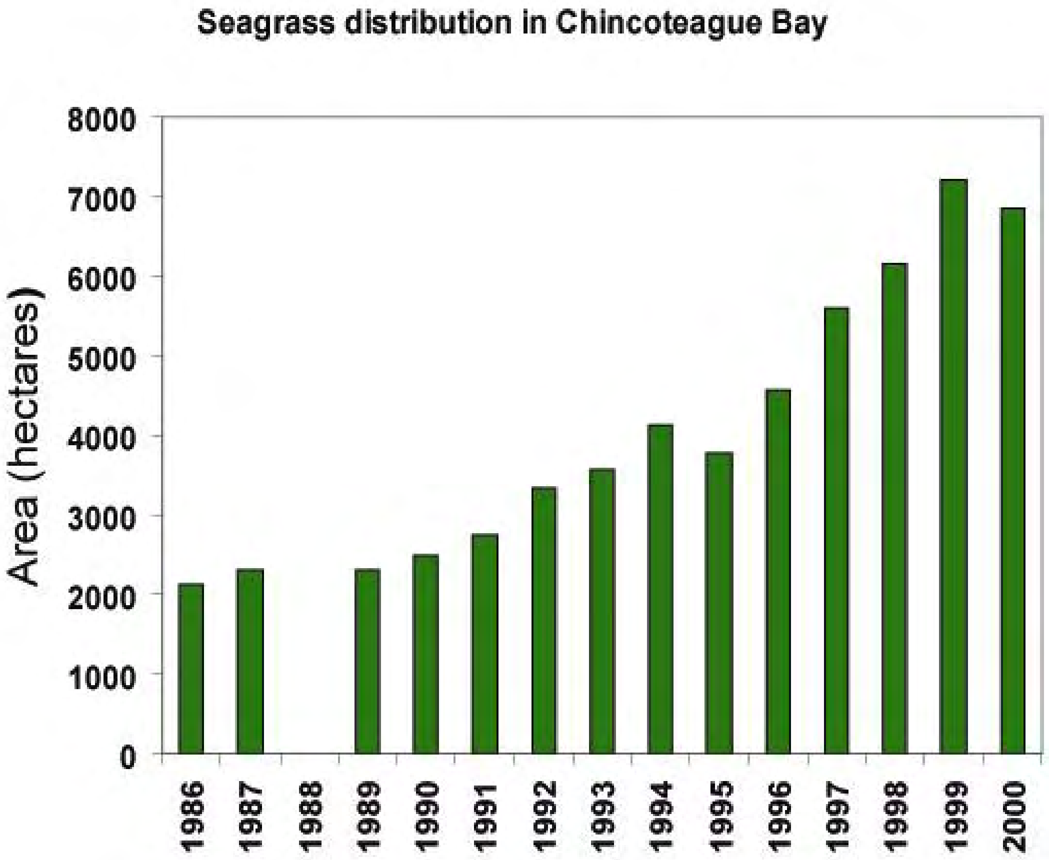


Figure 1 Submerged aquatic vegetation (SAV) in Chicoteague Bay taken from Virginia Institute of Marine Science overflight data (see http://www.vims.edu/bio/sav/index.html).

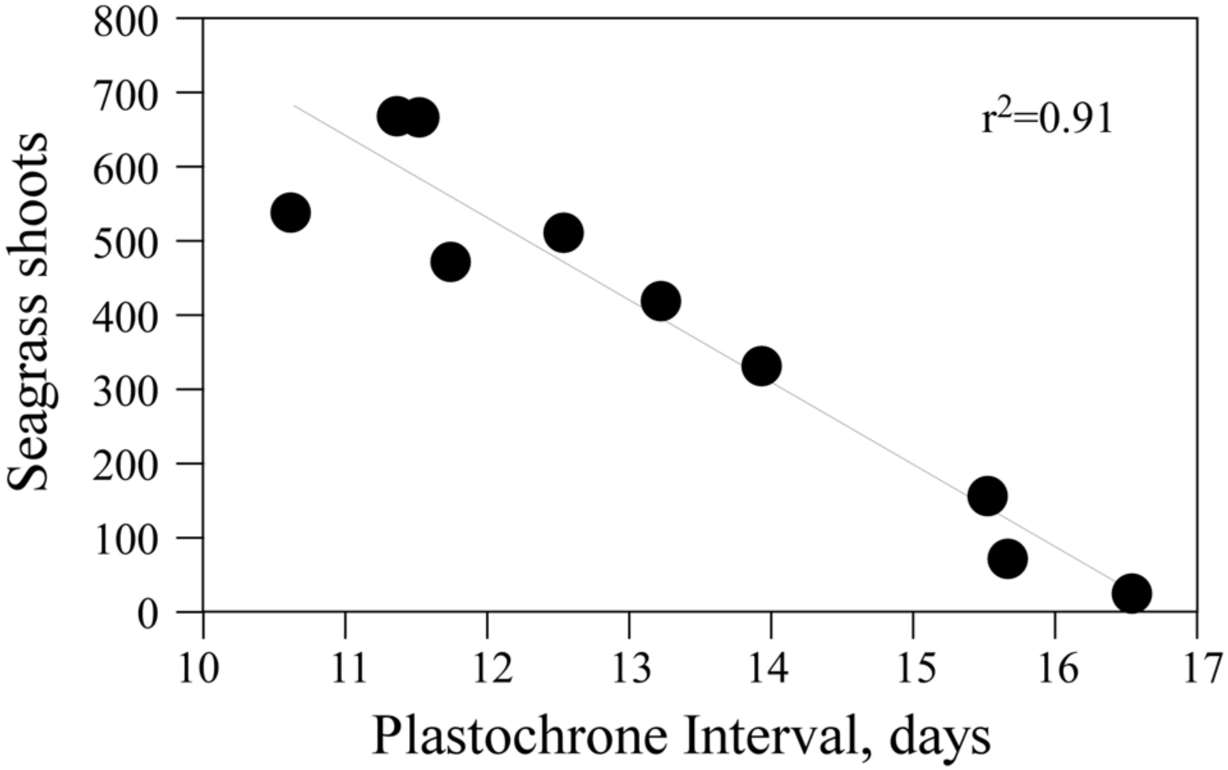


Figure 2. The results of a mesocosm experiment (April-September, 1999) indicating that the plastochrone interval, one of our assessment tools, is inversly related to the number of plants remaining on September 1, 1000. All treatments were planted at 450 shoots m-2 in April 1999.

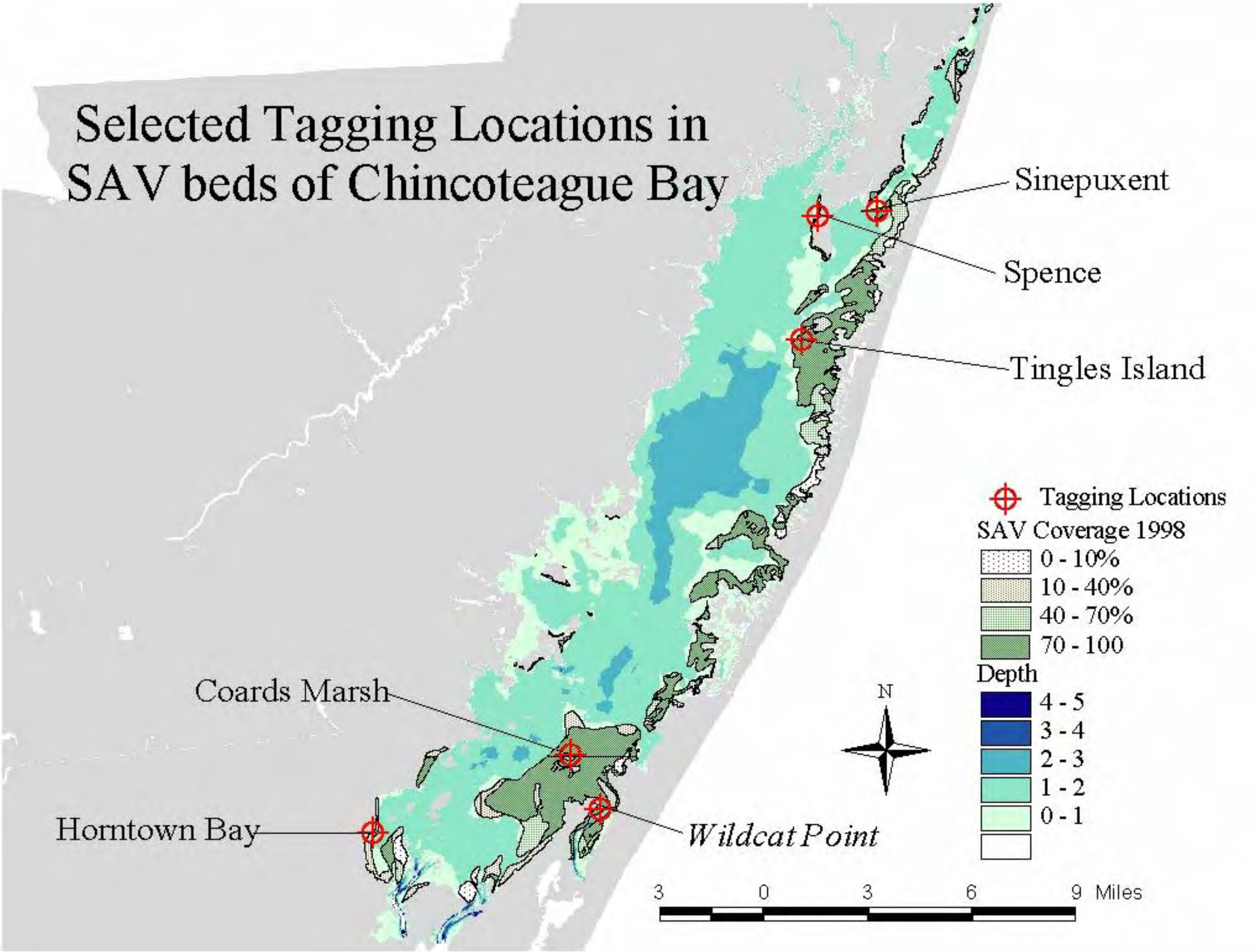


Figure 3. Selected tagging locations in SAV beds of Chincoteague Bay.

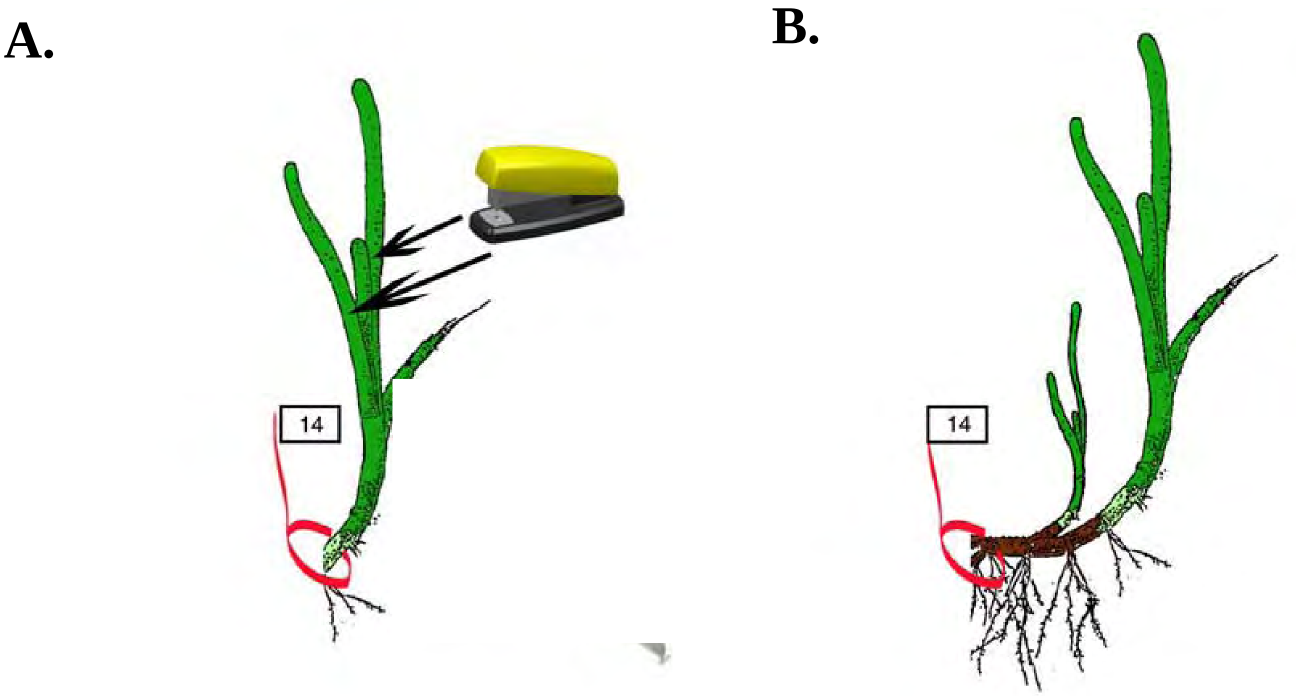


Figure 4. Schematic of tagging technique used to measure eelgrass production. Picture A describes initial tagging. Picture B describes plant growth after 30-day tagging period.

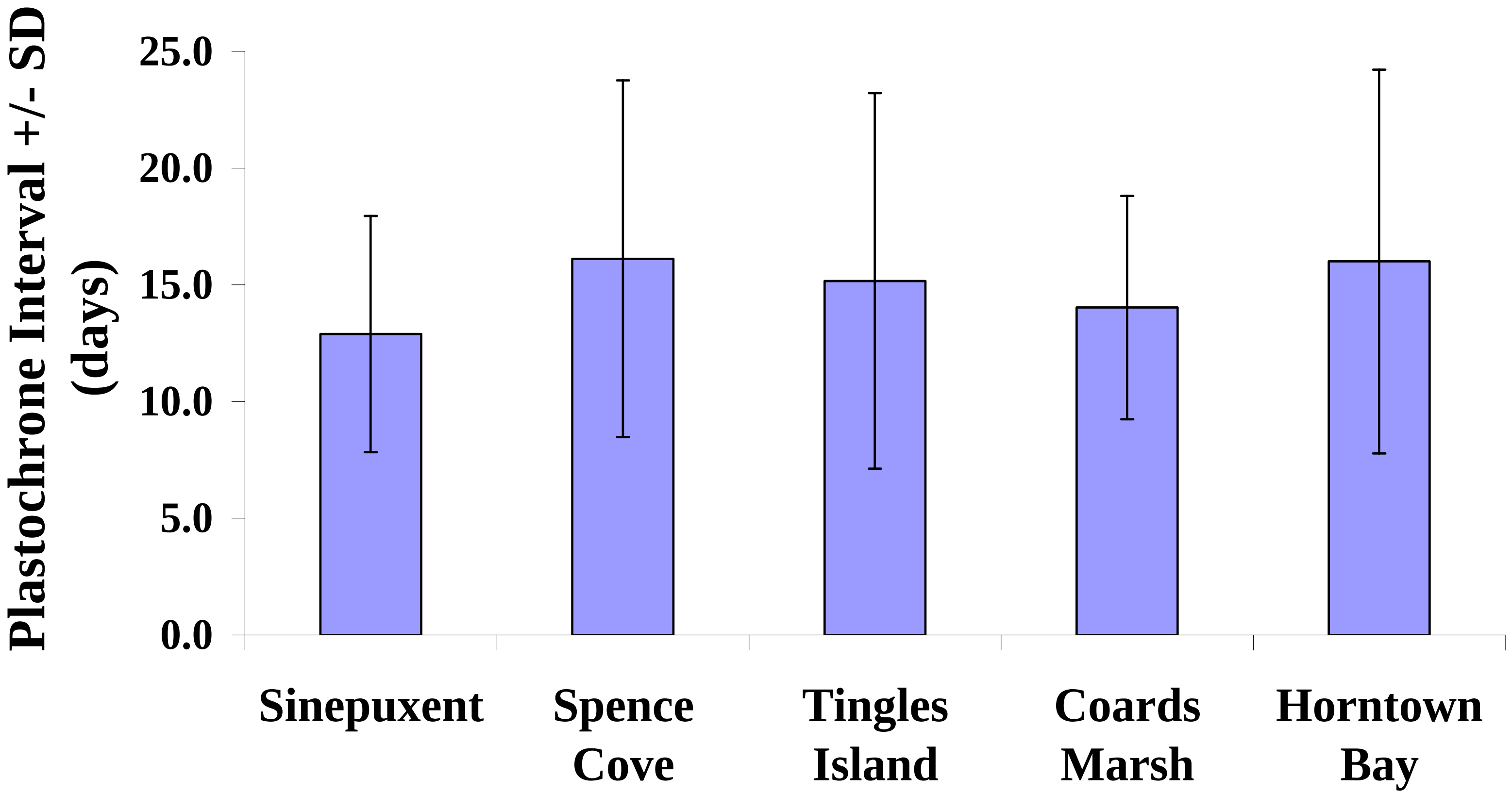


Figure 5. Mean (+/- SD) Plastochrone Interval Measured at Tagging Sites in the Coastal Bays, 2001.

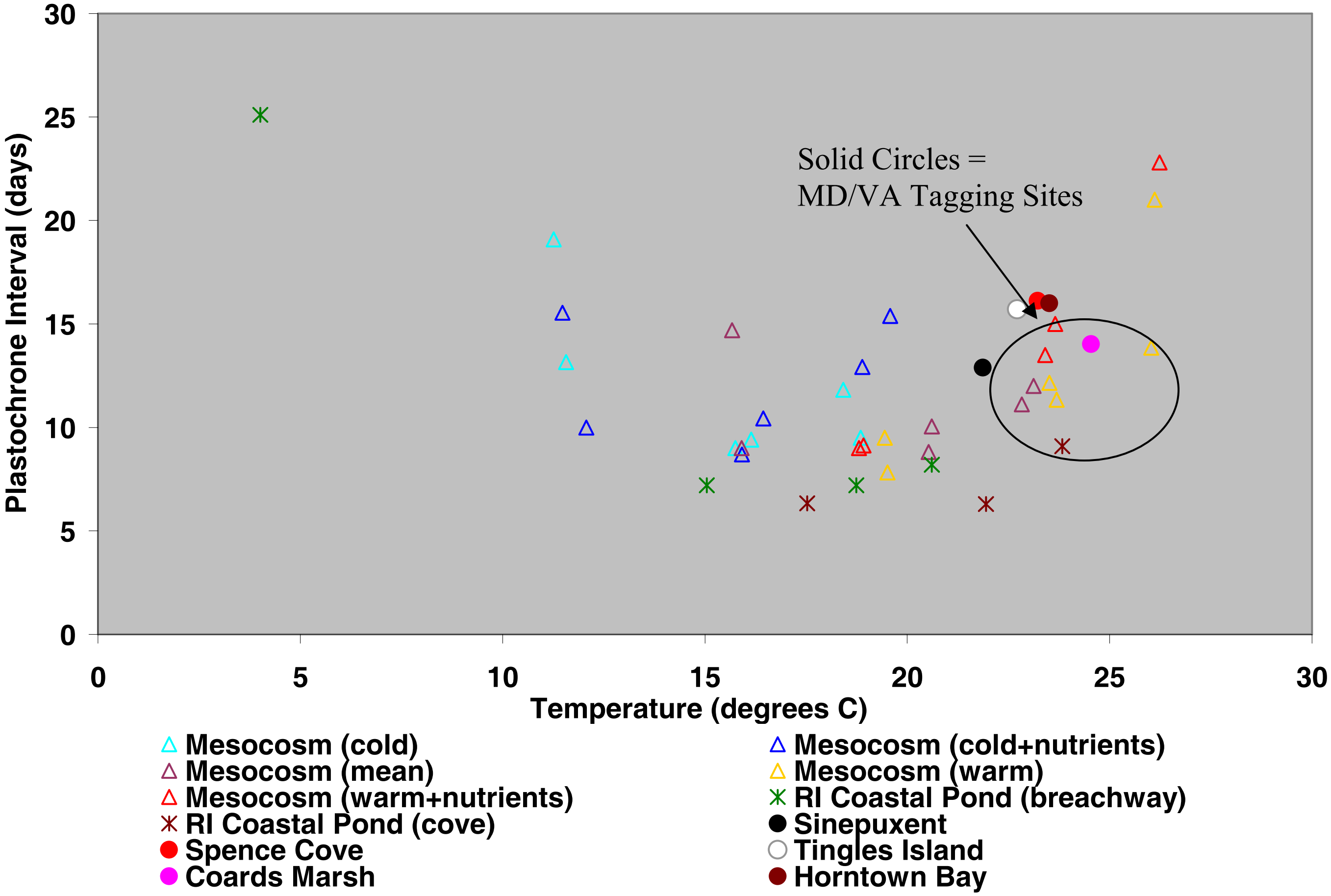


Figure 6. Comparison of 2001 MD/VA Coastal Bays plastochrone intervals with results of RI mesocosm temperature and nutrient experiments. Field measurements from a RI Coastal Pond are also included.

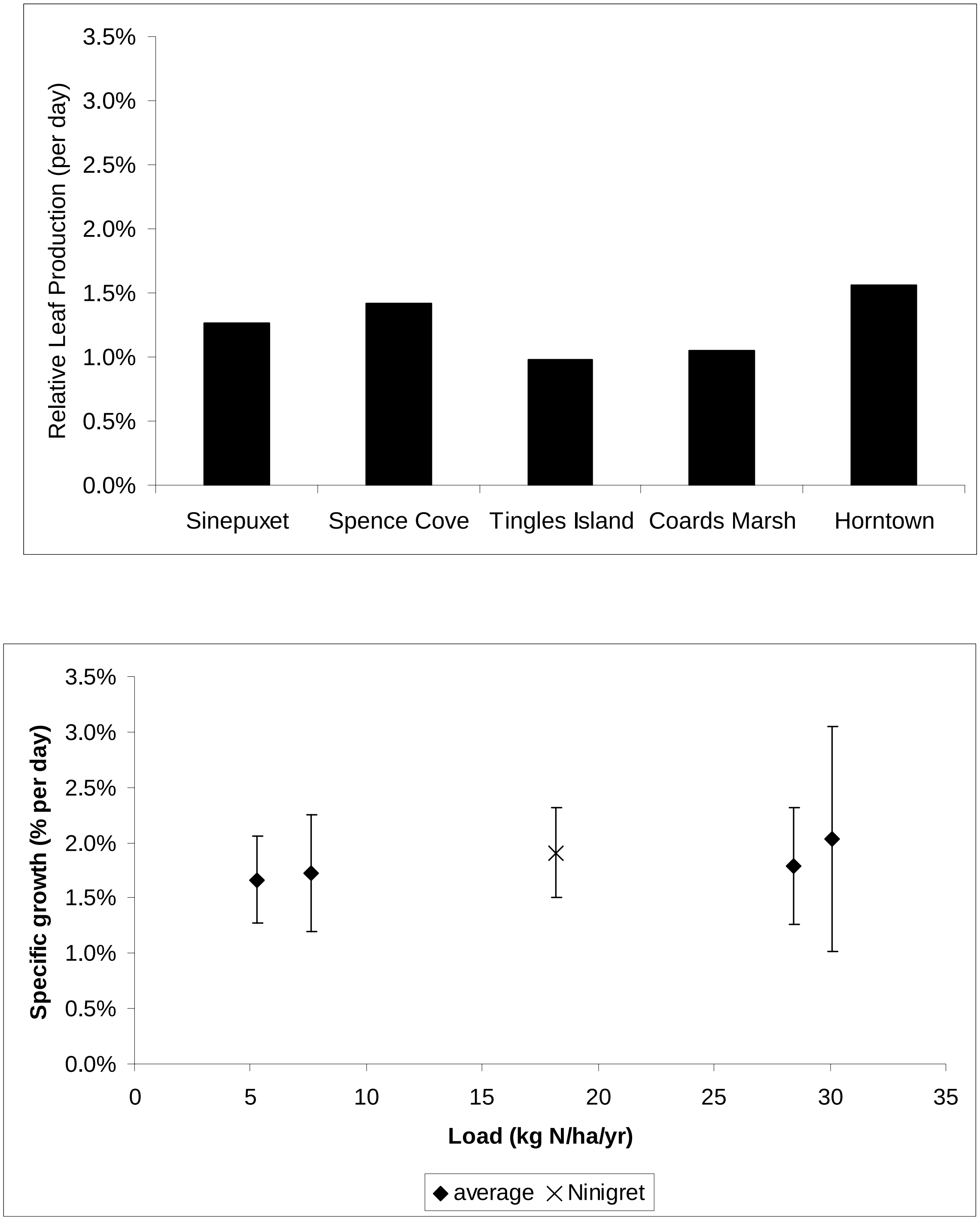


Figure 7. Relative Growth Rates of New England eelgrass (bottom) and MD/VA Coastal Bays (top).

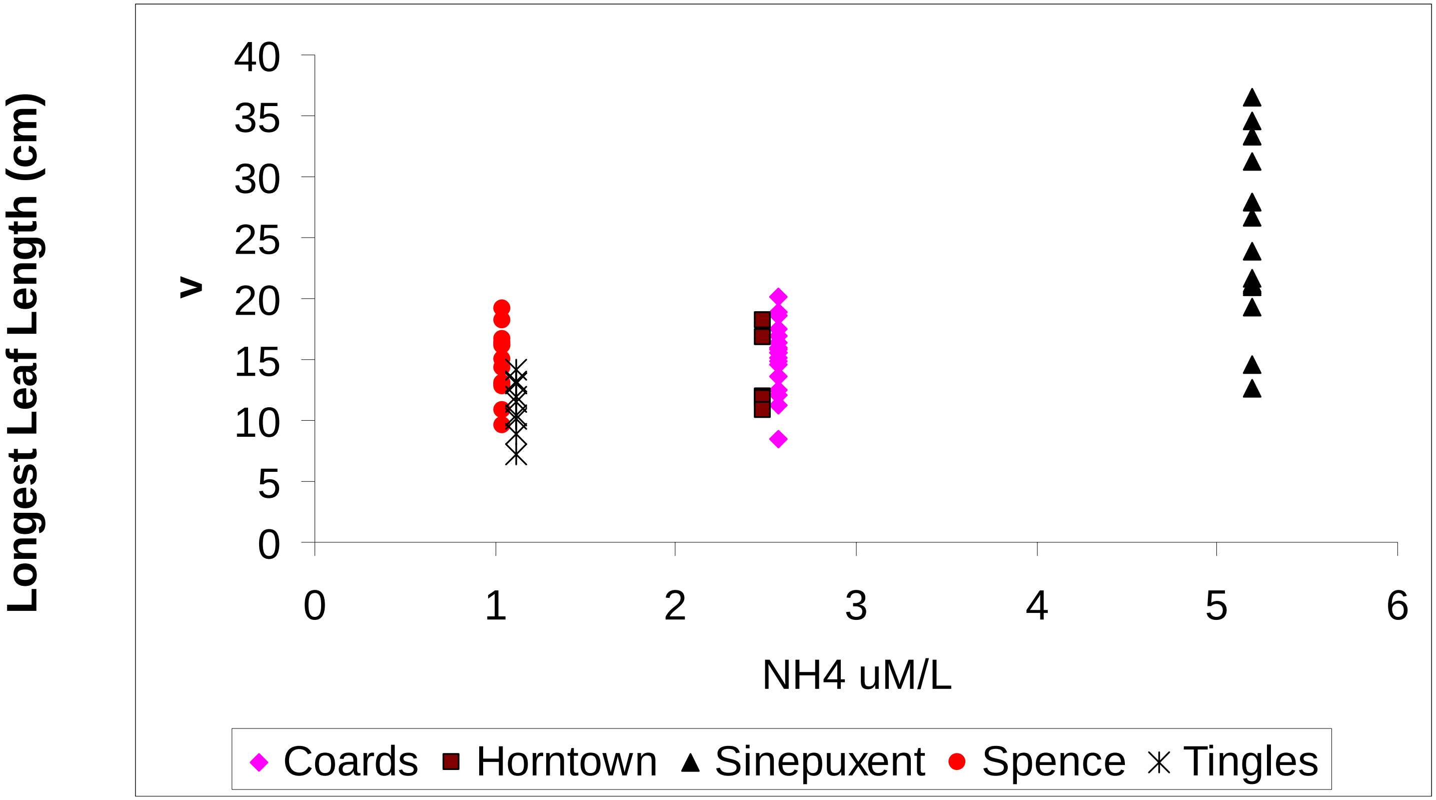


Figure 8. Longest Leaf Length versus NPS monitoring station water column NH_4 concentration.

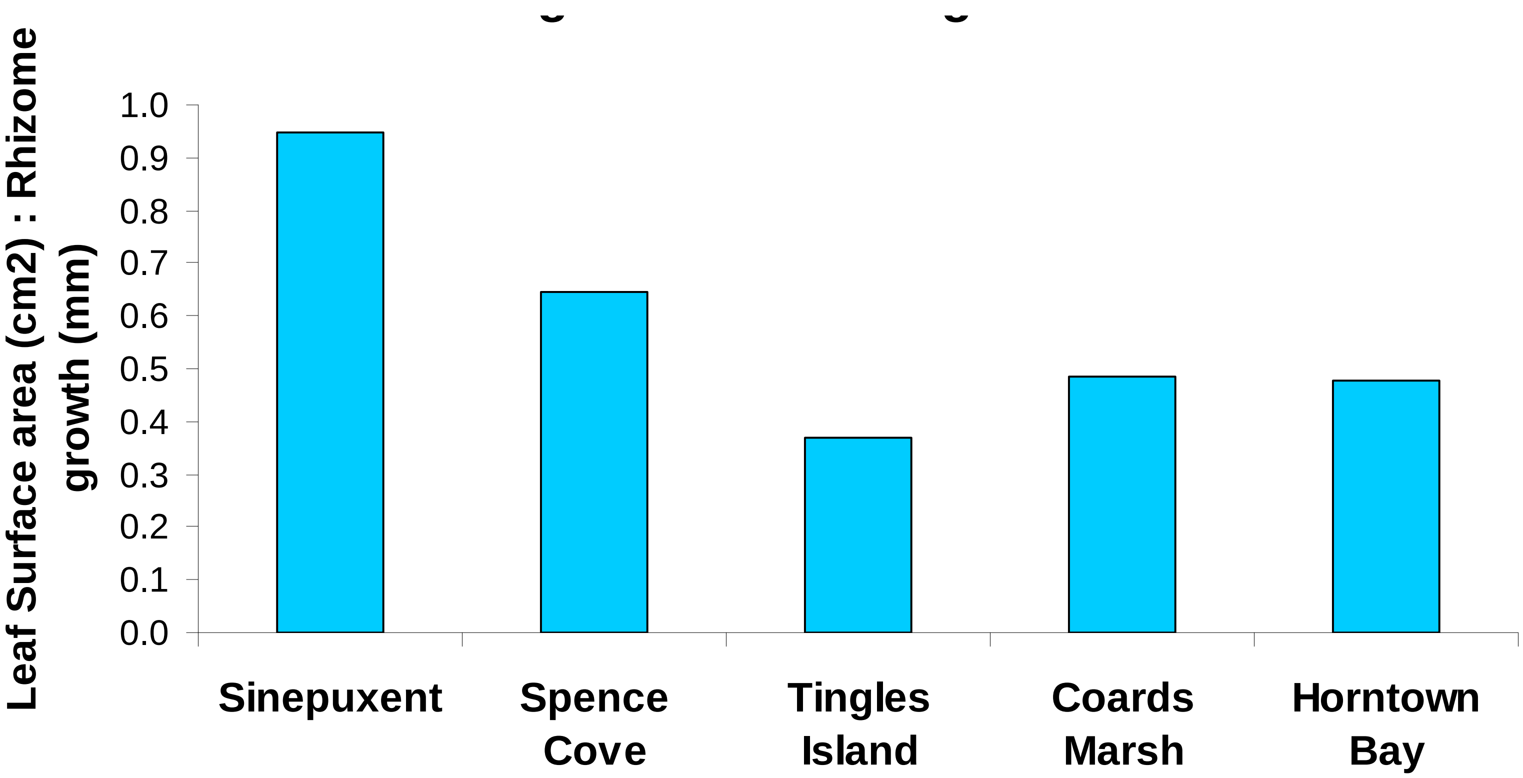


Figure 9. Mean Ratio of Leaf to Rhizome at Tagging Sites in Coastal Bays, 2001.

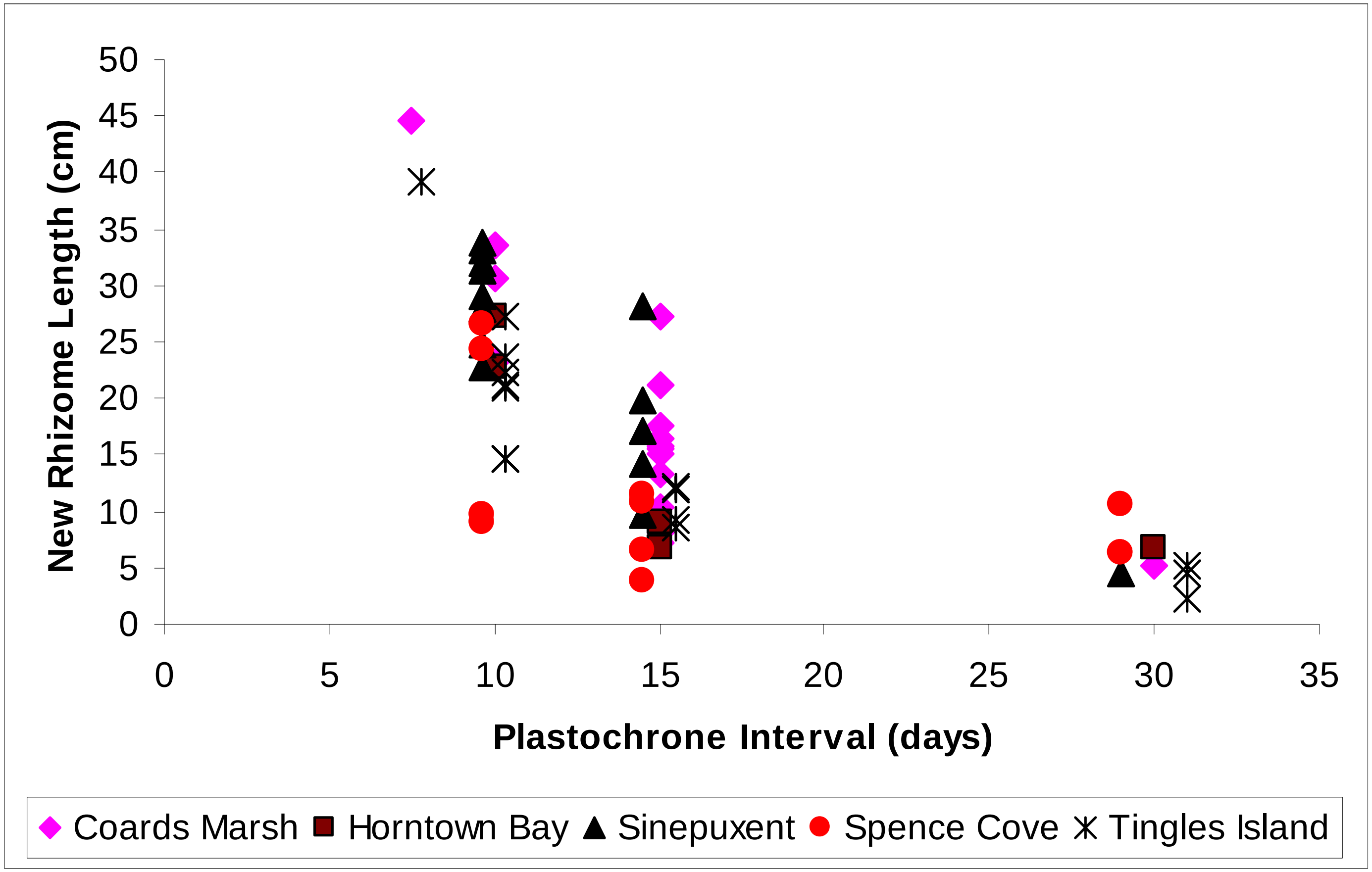


Figure 10. New Rhizome Production versus Plastochrone Interval measured at tagging sites in the Coastal Bays, 2001.

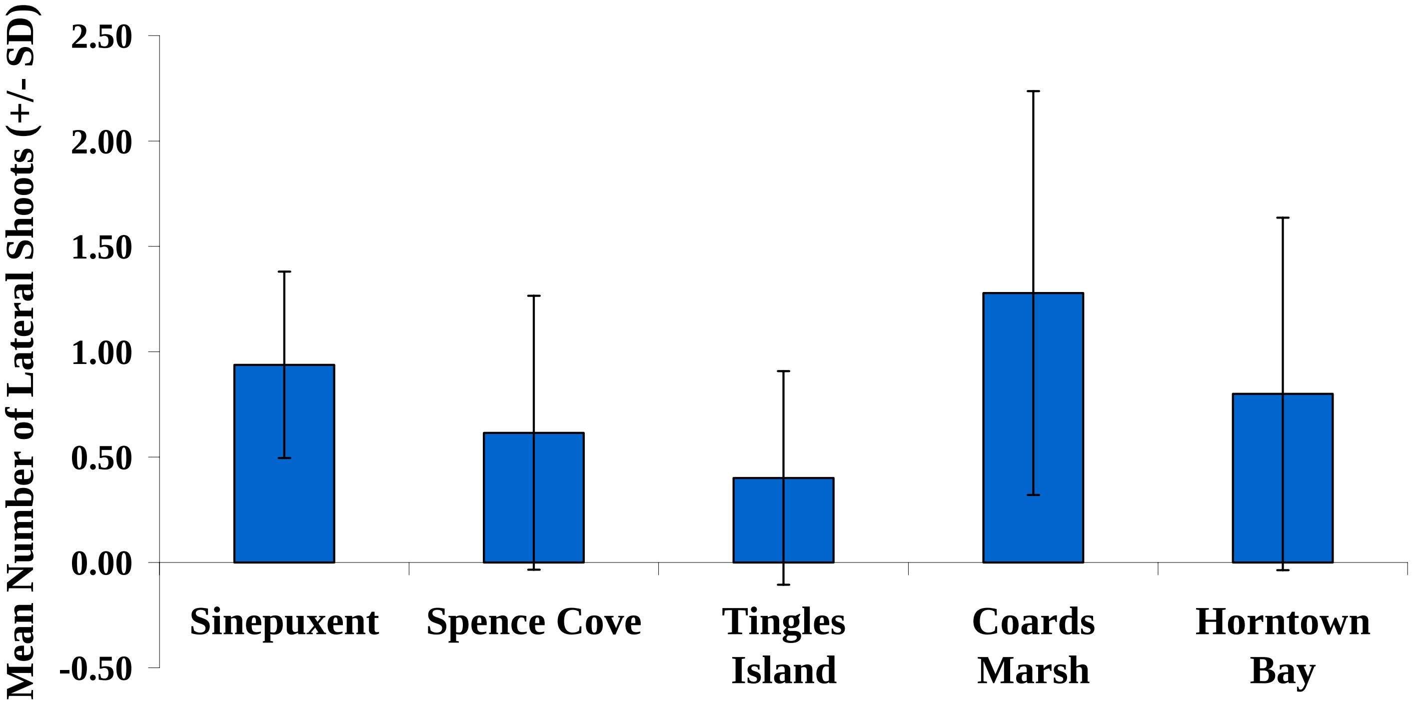


Figure 11. Mean (+- SD) Lateral Shoots Produced at Tagging Sites in Coastal Bays, 2001.

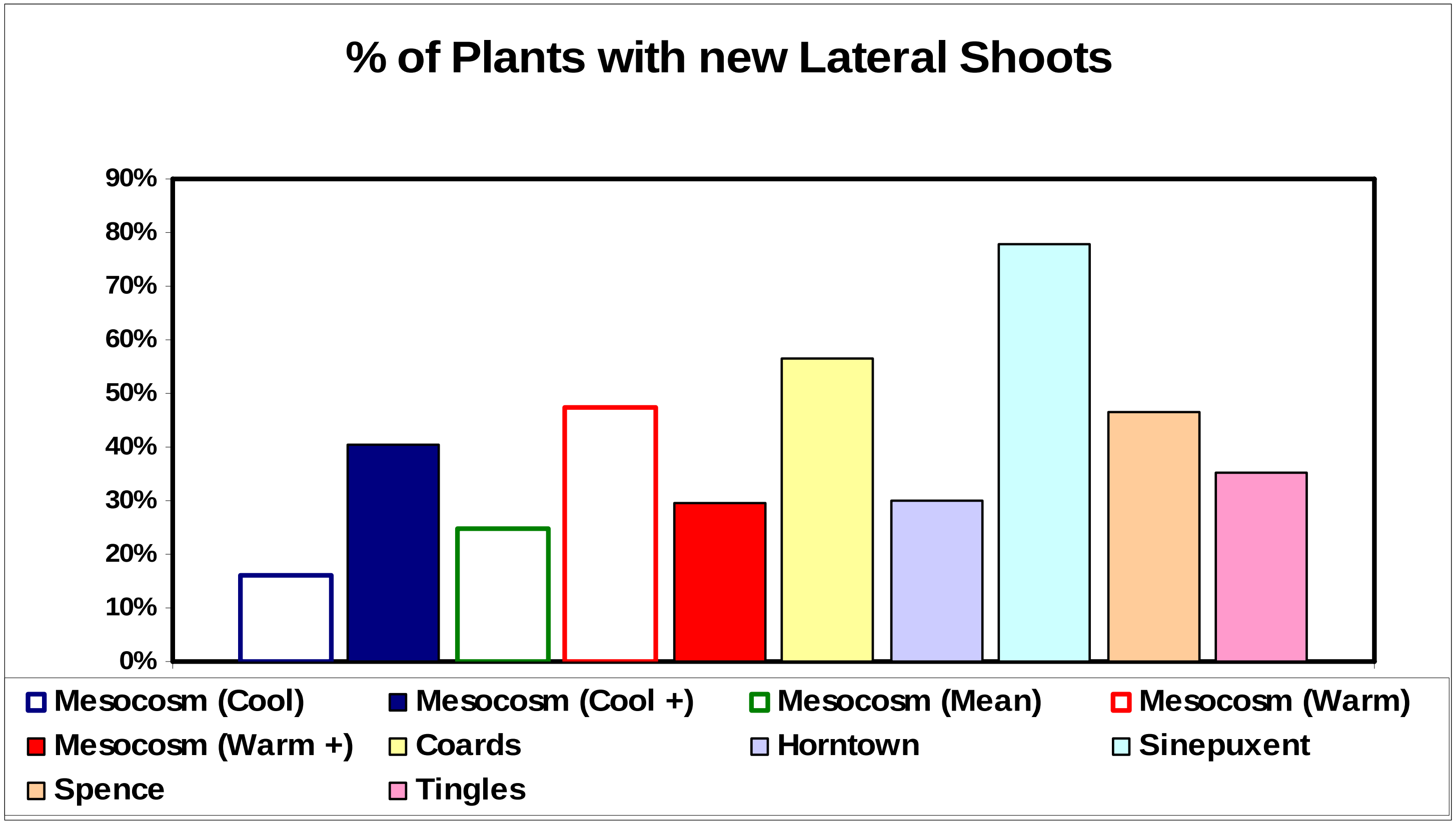


Figure 12. Percentage of tagged plants producing new lateral shoots in Mesocosm experiments and MD/VA Coastal Bays, 2001.

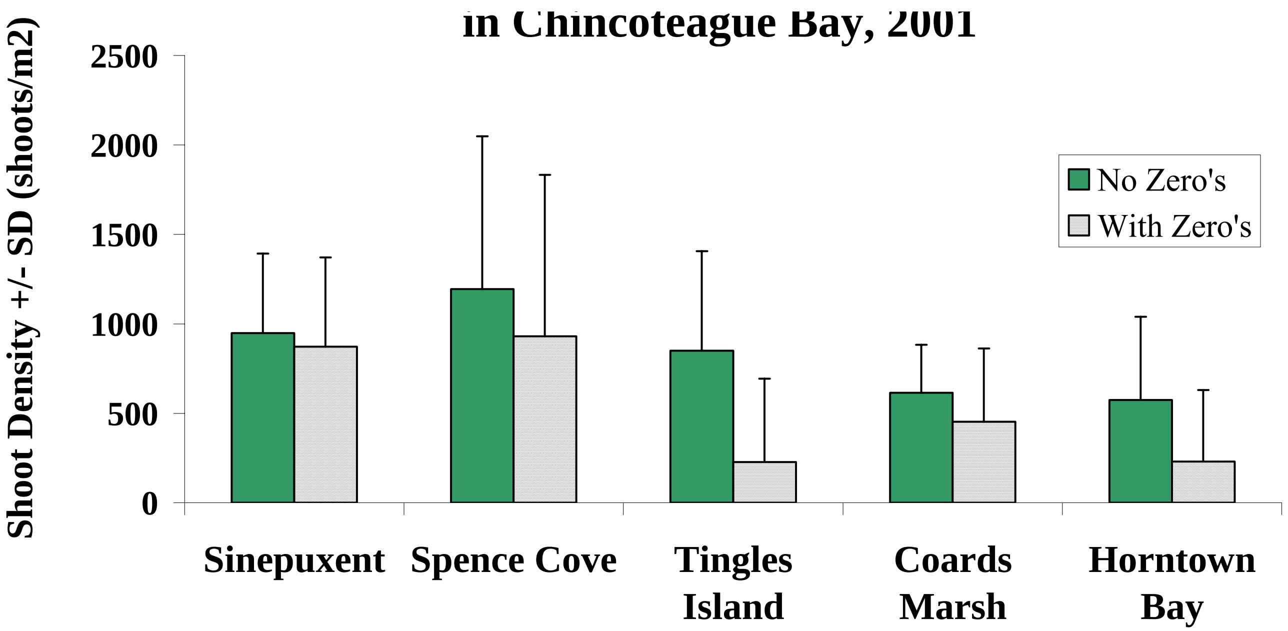


Figure 13. Mean (+/- SD) Shoot Density at Tagging Sites in Coastal Bays, 2001.

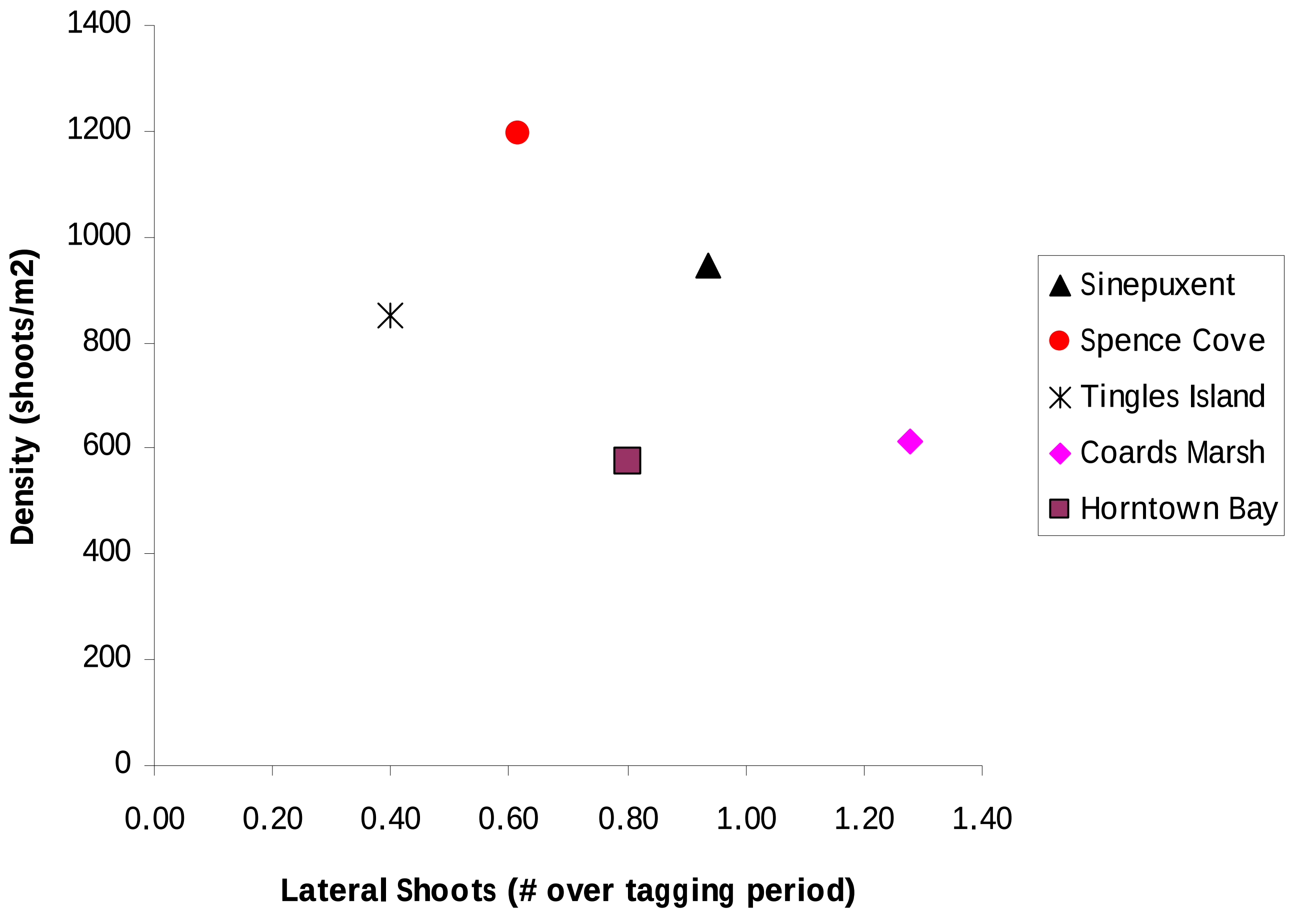
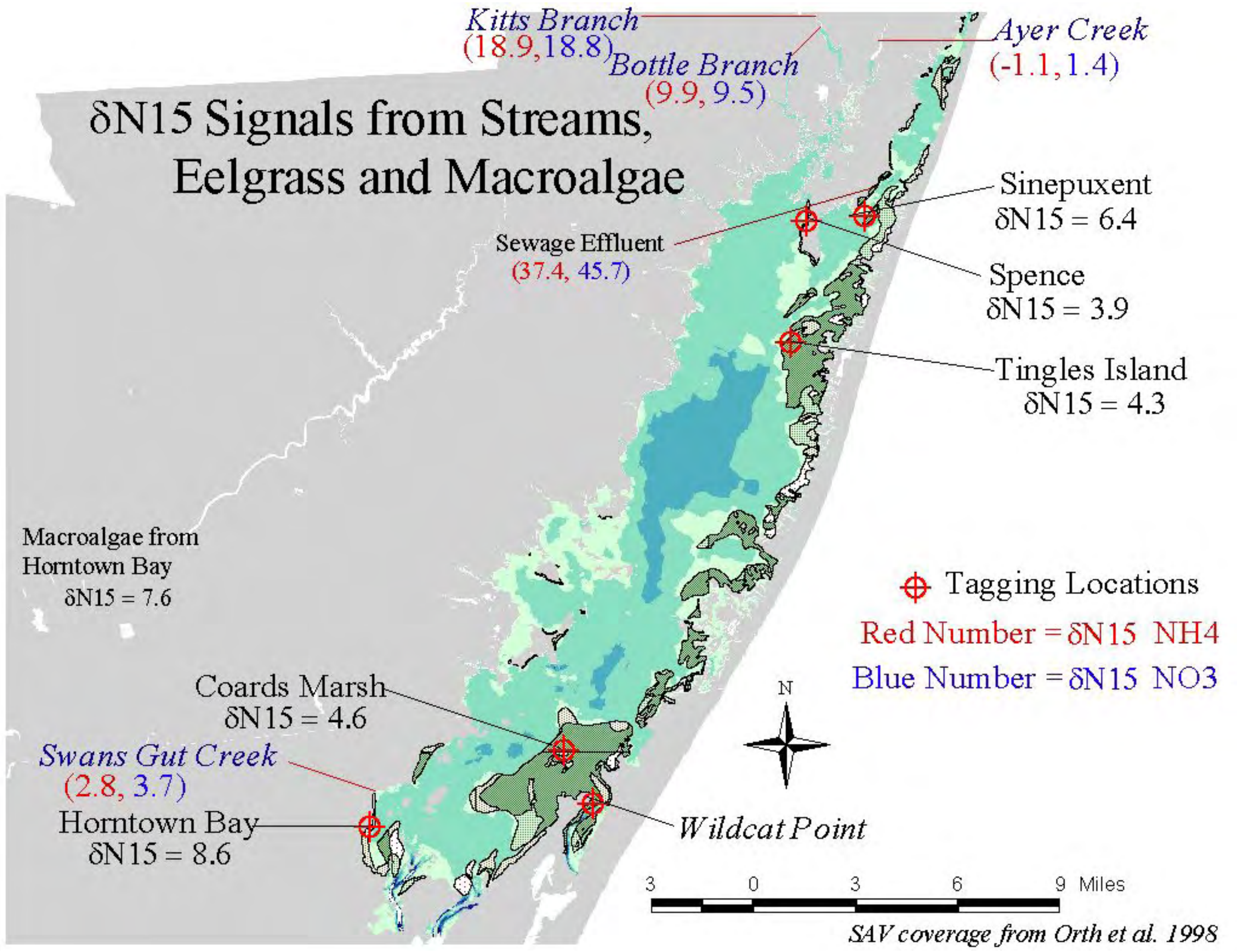


Figure 14. Mean (+/- SD) Shoot Density versus Lateral Shoot Production at Tagging Sites in Coastal Bays, 2001.



SAV coverage from Orth et al. 1998

Figure 15. δN15 Signals from Streams, Eelgrass and Macroalgae.

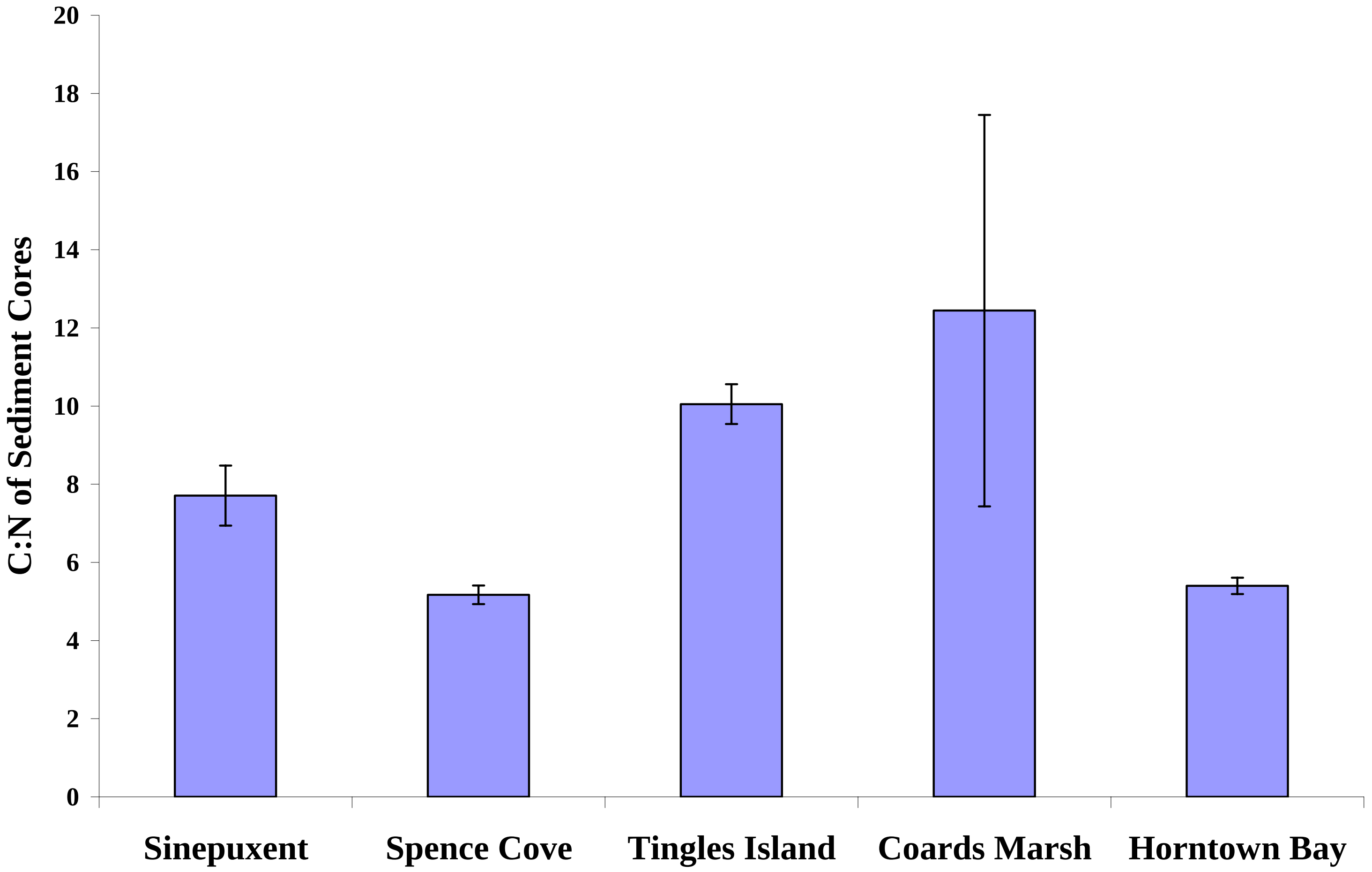
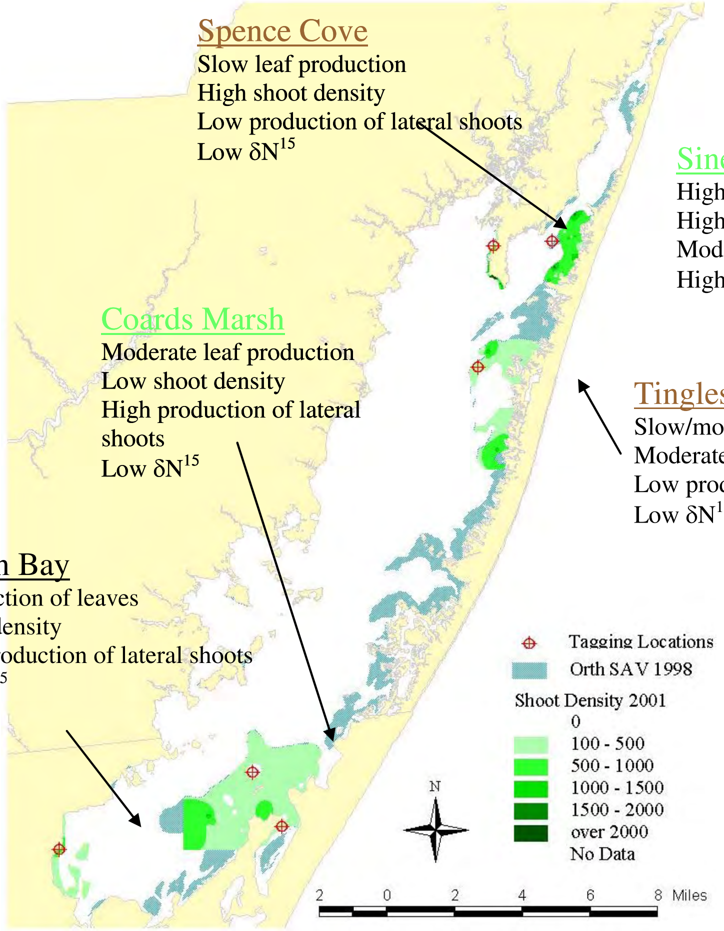


Figure 16. Mean (+/- SD) Sediment Core C:N at Tagging Sites in Coastal Bays, 2001.



Spence Cove
Slow leaf production
High shoot density
Low production of lateral shoots
Low δN^{15}

Sinepuxet Marker 25
High leaf production
High shoot density
Moderate roduction of lat. shoots
High δN^{15}

Coards Marsh
Moderate leaf production
Low shoot density
High production of lateral shoots
Low δN^{15}

Tingles Island
Slow/moderate leaf production
Moderate shoot density
Low production of lateral shoots
Low δN^{15}

Horntown Bay
Slow production of leaves
Low shoot density
Moderate production of lateral shoots
Highest δN^{15}

Figure 17. Summary Evaluation of Measured Parameters in Coastal Bays during Summer 2001.

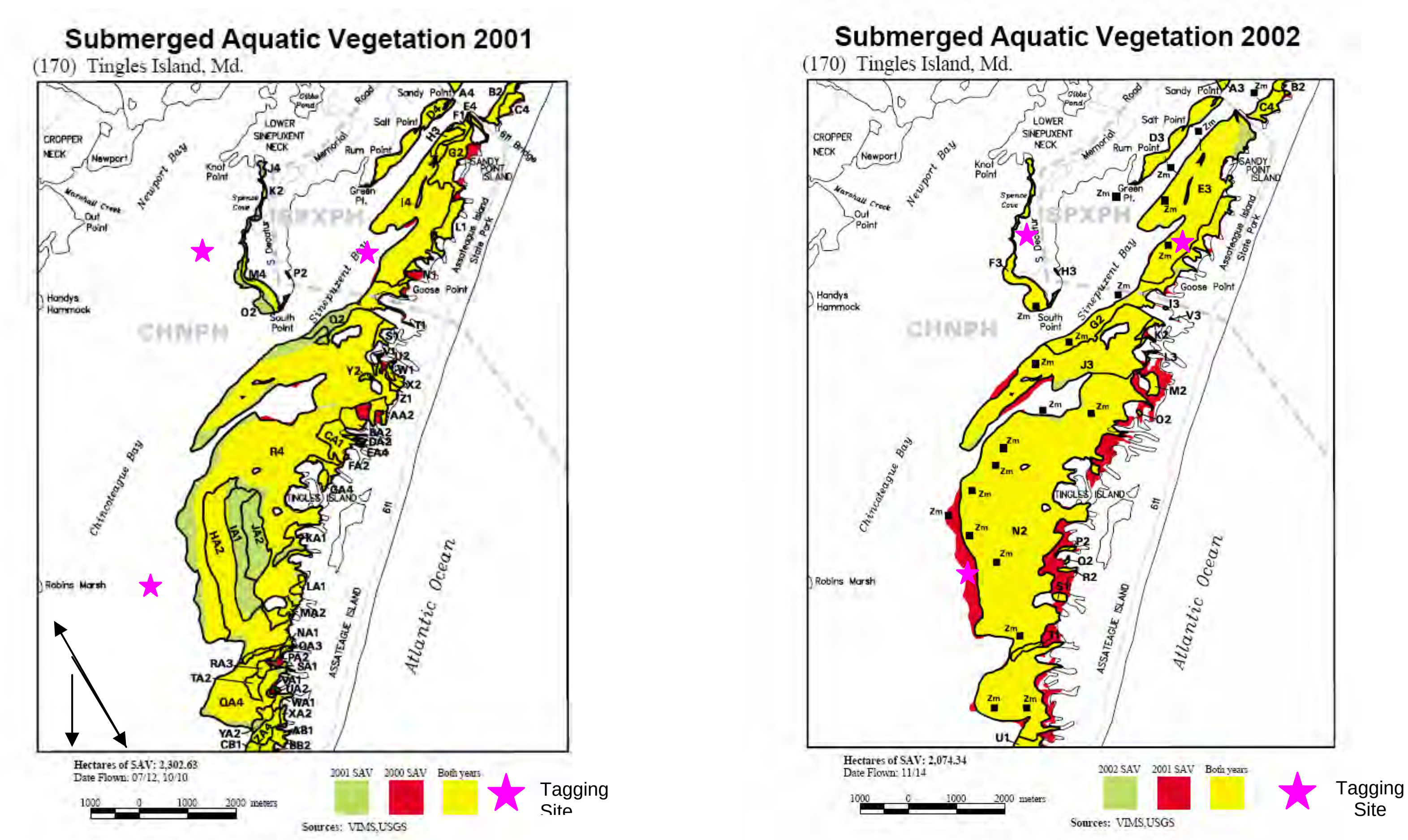


Figure 18. Comparison of SAV coverage between 2000, 2001, and 2002. Maps from Special Reports #139 and #143 published by the Virginia Institute of Marine Science. Available at: http://www.vims.edu/bio/sav/ Tagging Sites represent estimated locations for Spence, Sinepuxent, & Tingles Island sites.

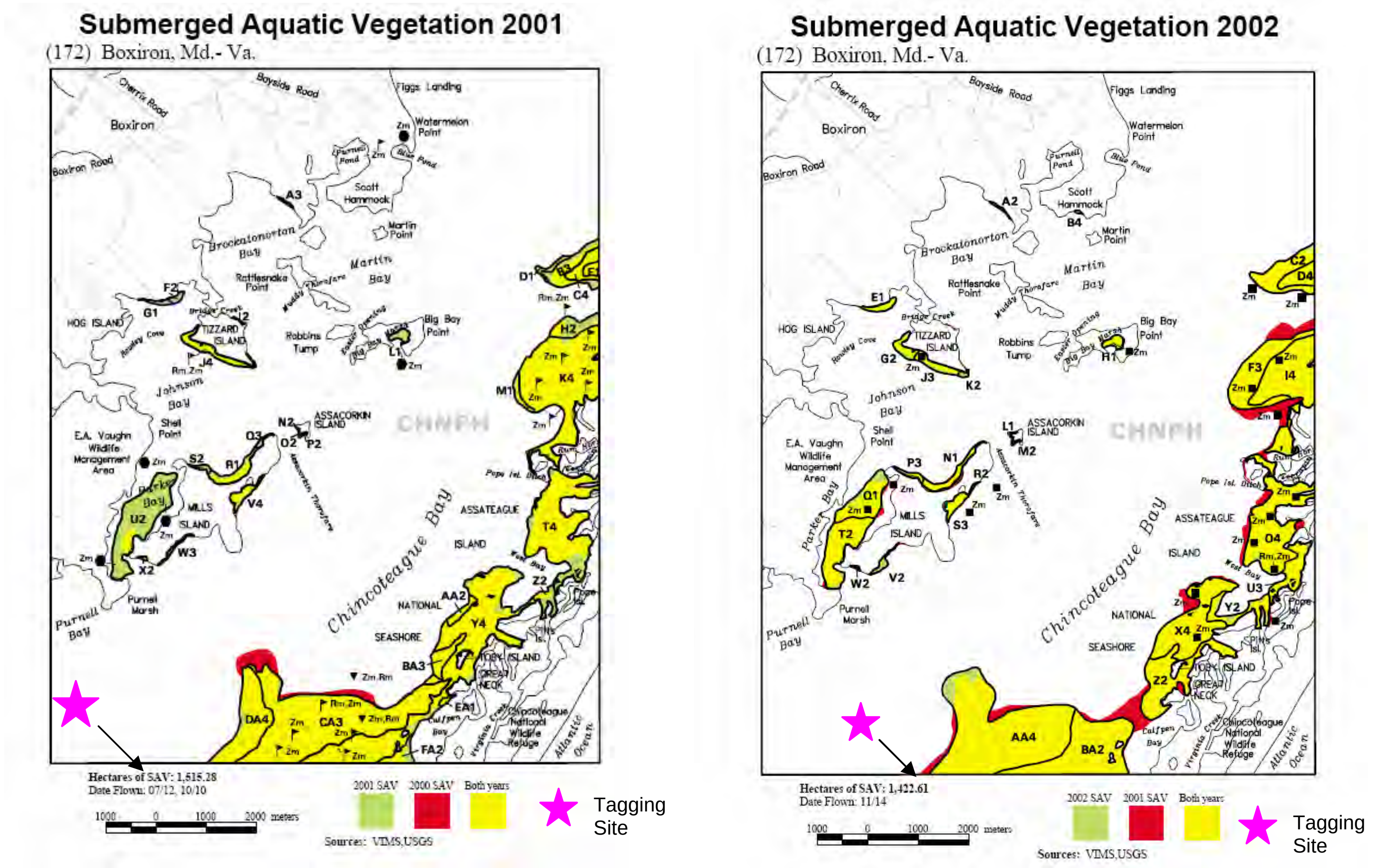


Figure 19. Comparison of SAV coverage between 2000, 2001, and 2002. Maps from Special Reports #139 and #143 published by the Virginia Institute of Marine Science. Available at: http://www.vims.edu/bio/sav/. The Coards marsh site is just south of the border for this mapping unit.

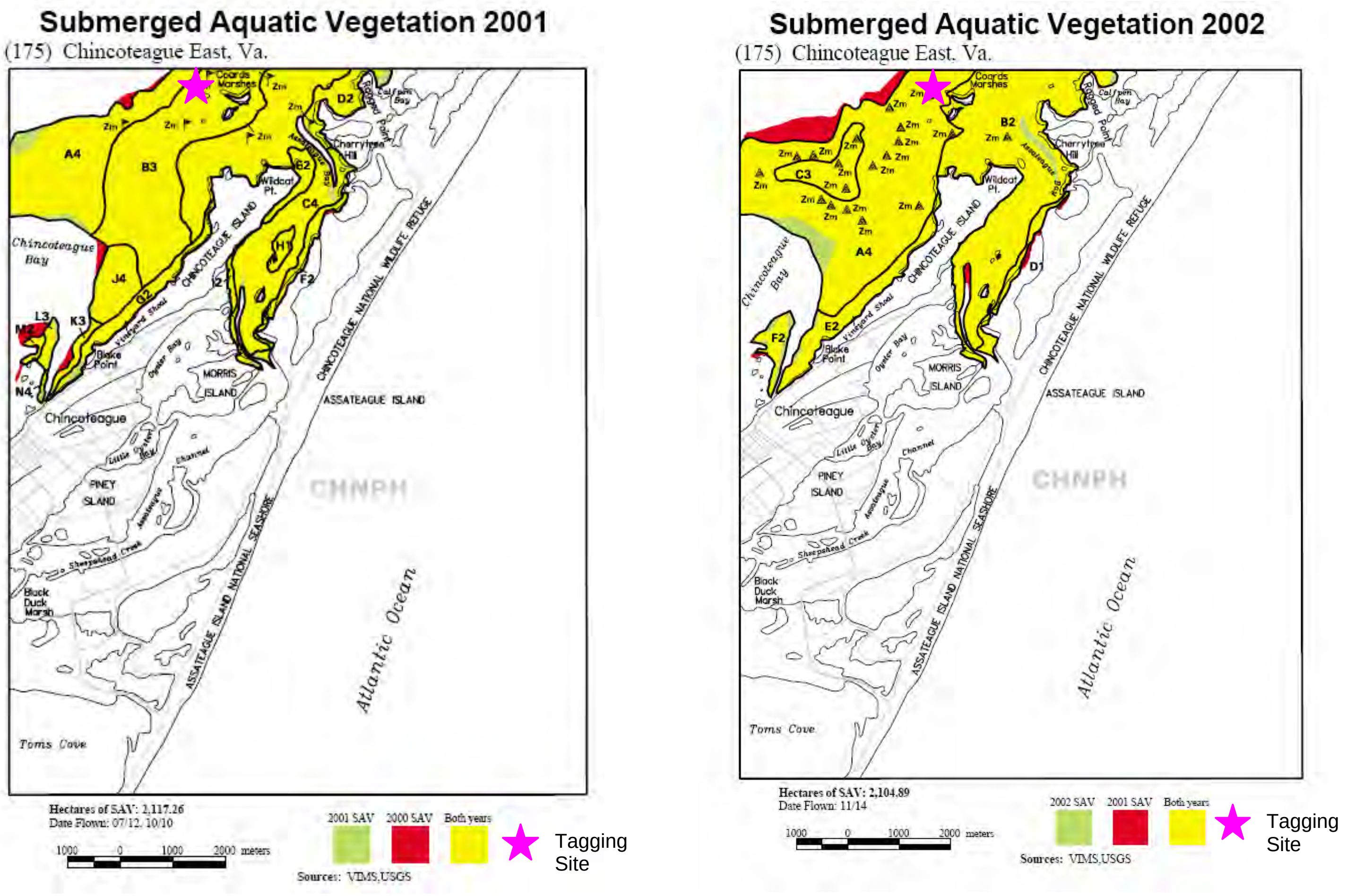


Figure 20. Comparison of SAV coverage between 2000, 2001, and 2002. Maps from Special Reports #139 and #143 published by the Virginia Institute of Marine Science. Available at: http://www.vims.edu/bio/sav/ Star represents estimated tagging site at Coards Marsh .

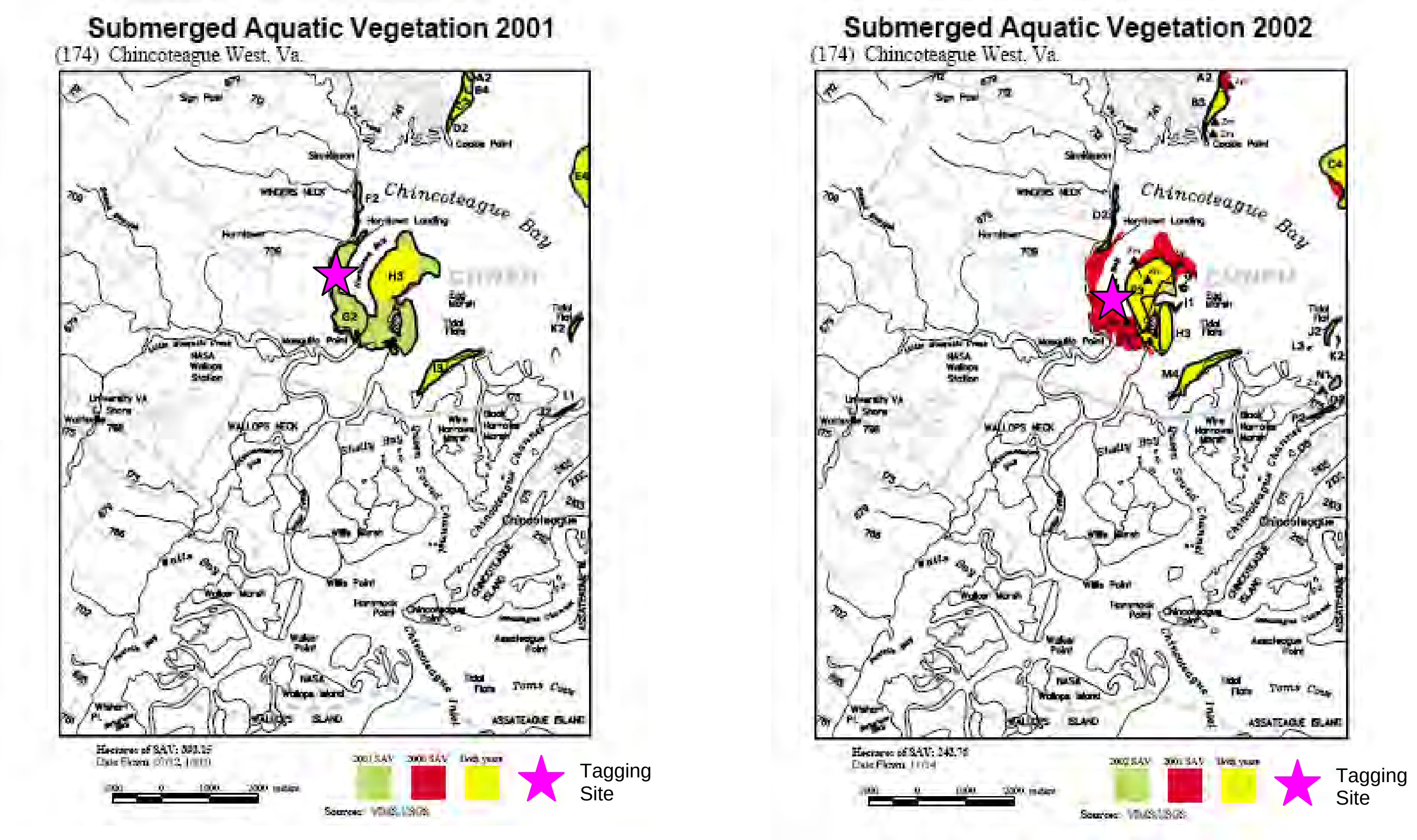


Figure 21. Comparison of SAV coverage between 2000, 2001, and 2002. Maps from Special Reports #139 and #143 published by the Virginia Institute of Marine Science. Available at: http://www.vims.edu/bio/sav/
Star represents estimated tagging site in Horntown Bay.

NPS D-103 March 2007

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