NERRS SWMP Bio-Monitoring Protocol

Long-term Monitoring of Estuarine Submersed and Emergent Vegetation Communities

National Estuarine Research Reserve System
Technical Report

SAV-Emergent Biomonitoring Committee
Chair, Dr. Kenneth Moore, Research Coordinator
Chesapeake Bay National Estuarine Research Reserve System in Virginia
Gloucester Point, VA 23062

December 2009

Introduction

Macrophyte communities including tidal wetlands and submersed macrophyte beds are important components of estuarine ecosystems. They form a buffer between upland systems and the sea and provide complex habitats with irreplaceable value to both coastal systems and their adjacent watersheds. They also serve as important sites for education as well as recreation and are critical components of the National Estuarine Research Reserve System.

Despite their currently recognized values, the distribution, abundance and diversity of these communities have been lost as a direct result of human impact. For example, nearly 50% of the coastal wetlands have been lost in the United States through dredging and filling activities (Dahl 1990). Changes in hydrological regimes through alterations in drainage (Niering and Warren 1980) or tidal flushing patterns (Roman et al. 1984) as well as local subsidence (Davis 1987) have severely impacted many others. In the Chesapeake Bay region beds of submersed aquatic vegetation are currently at their lowest levels of abundance in recorded history (Orth and Moore 1983) and these declines can be directly related to watershed inputs of sediments and nutrients accelerated by human activities (Kemp et al. 1983; Brush 2001).

Natural forces can also have significant influences on these vegetation systems. Storms can be powerful forcing functions modifying these areas over both the short and long term (Davis 1987; Short and Wyllie-Echeverria 1996; Roman et al. 1997). Sea level rise or other changes in water level, as well as global climate change can have a wide range of effects on both submersed and emergent coastal plant communities including: submergence and drowning, changes in salinity, temperature, runoff and water quality, as well as increasing UV radiation (Warren and Niering 1993; Watson et al. 1996; Short and Neckles 1999). Additionally, non-indigenous or invasive plant species can have significant impacts on the structure and function of these habitats (Sandlund 1999).

Restoration of emergent and submersed aquatic vegetation (SAV) communities is a major management goal in most developed estuarine areas and is an important initiative of NOAA and NERRS (NOAA/NOS 1999). Further, the process of natural recovery of systems impacted by extreme events such a hurricanes can be of significant interest. Evaluating the success of restoration efforts, as well as assessing the recovery of impacted communities requires detailed, statistically rigorous, protocols that can be equally applied to both reference areas and impacted sites. Periodic, consistent, long-term monitoring of unimpacted or reference sites can also provide measures of natural variability that are very useful in evaluating restoration efforts or recovery from perturbation.

Evaluating habitat change of vegetation communities can be accomplished at various levels of detail in the landscape. Comprehensive, broad evaluation of habitats typically requires the use of airborne or satellite remote sensing tools and imagery. Ground surveys, although not a replacement for remote imagery, provide a level of detail for assessing community composition and change that is complementary to broader scale remote surveys. Additionally, the implementation of statistically rigorous ground surveys can provide a foundation for other monitoring activities related to quantifying the process of change in these communities.

The objectives of this monitoring protocol for emergent and submersed vegetation communities:

1. Are designed to quantify vegetation patterns and their change over space and time;

2. Are consistent with other monitoring protocols used nationally and worldwide;

3. Can be consistently used over a wide range of estuarine sites and habitats, and for a variety of reserve specific purposes;

4. Can be used as a foundation for quantifying relationships among the various edaphic factors and the processes that are regulating the patterns of distribution and abundance in these communities;

5. Provide detailed information that can be used to support comprehensive remotely sensed mapping of vegetation communities and other NERRS System Wide Monitoring Program data collection, as well as NERRS/NOAA education, stewardship and restoration efforts.

Methods

The approach consists of fixed transects with permanent sampling stations located along transects that can be stratified, if necessary, within vegetation zones or segments of the marsh or submersed vegetation beds. This approach has been used in a variety of studies for assessments of vegetation communities (Doumlele 1981; Moore et al. 1995; Perry and Atkinson 1997; Perry and Hershner 1999) and has been recently adopted as a monitoring protocol by the National Park Service and others to assess and compare both reference and restoration wetland sites on local and regional scales (Neckles and Dionne 2001; Roman et al. 2001; Neckles et al. 2002). Additionally, similar protocols have been established for quantification of seagrass dynamics in a global seagrass monitoring program (http://www.SeagrassNet.org; Short et al. 2002).

Site Selection

Control or reference sites in each study area are first identified as areas that have historically not been markedly impacted by natural or anthropogenic factors. The areas should also been representative of natural estuarine vegetation communities in the region. These determinations may have to be made using the best professional judgment of scientists based upon available information for each study area. The focus of this detailed vegetation monitoring can vary with the particular circumstances or goals for each study. For example, in the Chesapeake Bay Reserve in Virginia (CBNERRVA), a different emergent marsh community is associated with each of the four reserve sites (http://www.vims.edu/ cbnerr/reservesites/index.htm), and each encompasses a different salinity regime of the estuary. Each could serve as a reference site. However, since seagrass beds are known to be associated with only the most downriver site, the submersed macrophyte sampling would only be conducted there.

Other sites that represent some potential impacts that are of interest could also be established for comparative monitoring. Some potential impacts include:

1. Invasive or non-native species expansions.

2. Rare species declines

3. Changes in hydrology, geomorphic process, sea level rise or salinity intrusions.

4. Catastrophic impacts such as oil spills or storms.

5. Direct or indirect human impacts such as dredging, diking, filling or subsidence due to groundwater withdrawal or other factors.

6. Disease.

Similarly, emergent or submersed areas that currently, historically or in the future will be the focus of restoration efforts, either directly or indirectly through watershed modifications could be chosen for study. Other factors, such as those related to NERRS education or stewardship goals, could also be used in site selection. The objectives of monitoring each specific site should be chosen *a priori* for each study; however, the protocols provided here can be applied to additional sites chosen in the future. For example, if additional property were acquired and wetlands on that property were the focus of restoration efforts, the habitat change associated with those efforts could be quantitatively monitored over time or could be compared to an existing reference site if appropriate.

Si*te Delineation*

The emergent or submersed habitat of interest for study should be delineated and the boundaries defined *a priori*. A general base map should be developed providing the fundamental features of the site. The degree of detail of this reference map will be dependent on the extent of the geographical detail of the region. Typically, topographic quadrangles, digital orthophoto quarter quadrangles, vertical or oblique photographs can be used.

Stratification of a study area into segments of similar community type based upon the dominant environmental gradient may be necessary if a significant environmental or other gradient exists (Roman et al. 2001). For example an emergent creek marsh system dominated by an upstream-downstream salinity gradient or a restriction in tidal flushing could be stratified into two or more segments (Figure 1). Similarly a submersed aquatic vegetation community affected by a gradient of exposure (fetch), sediment type or some water quality characteristic such as salinity, or tide range could be stratified into several segments.

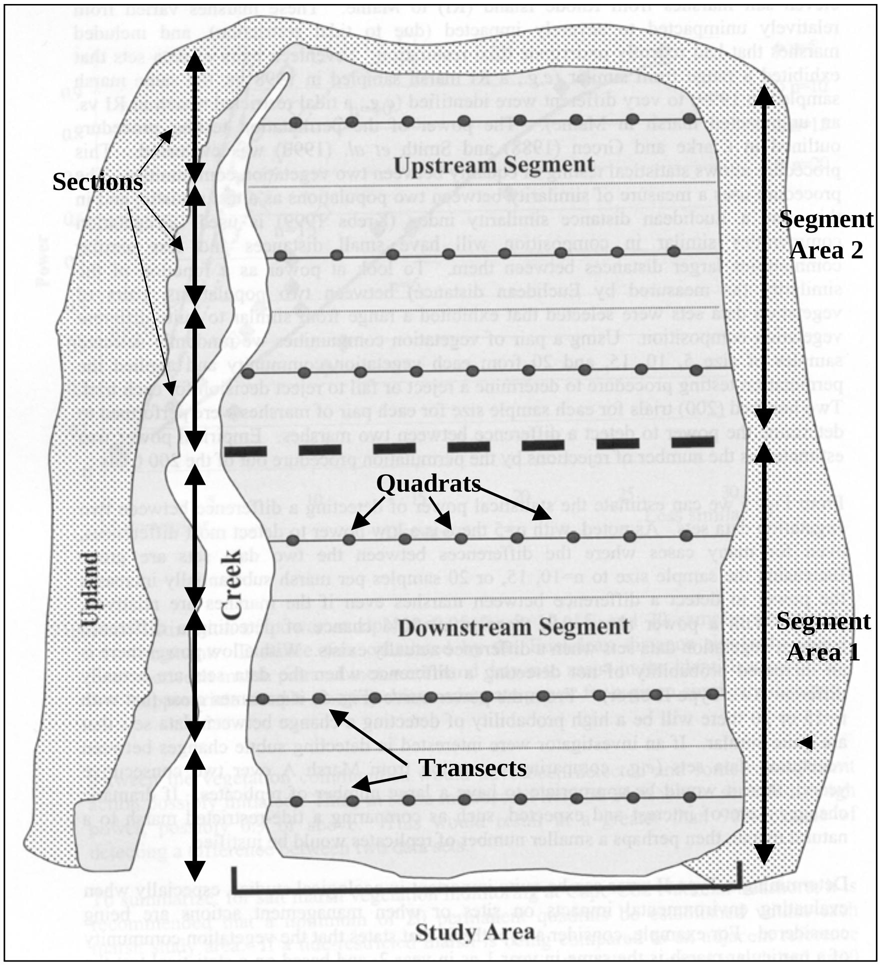

Figure 1. Emergent Marsh Sampling Design
(from Roman et al. 2001)

Emergent Vegetation Sampling Design

Each study area or segment of a study area may then be systematically divided into equal sized sections, if necessary (eg. for large study systems), to achieve good interspersion of samples throughout the area. One or two transects are then randomly located within each section so that a total of three to five transects will be located in a segment for a total of approximately 20 quadrats. Setting the random location of the sampling transects within a section can be accomplished by dividing the shoreline of each section into equal sized intervals, numbering each interval and then randomly choosing interval numbers for transect establishment using tables or computer random number generation. Individual transects should be no less than 10m apart to maintain independence and should cover an area that is representative of the segment. Each transect should traverse the elevation gradient from the creek bank to the upland. A detailed description of transect establishment for an emergent wetland study site using this approach is provided in Roman et al. 2001 (www.nature.nps.gov/im/monitor/protocoldb.cfm).

The first permanent plot on each transect should be randomly located within the marsh zone adjacent to the creek bank or open water ("creek marsh zone"). For example, if the creek marsh zone is only 3 m wide then this zone is divided into five 60 cm intervals and the first permanent quadrat is randomly located at the mid-point of one of the five intervals. Similarly, if the creek marsh zone is 30 m wide then the first quadrat is located randomly within the first 10 m of the transect. Each "permanent plot" is a area immediately adjacent to a specific point along the transect that is used for repeated vegetation sampling (Figure 2.).

The remaining permanent plots are then located at regular intervals along each transect. A total of approximately 20 plots per marsh segment are required for adequate sampling power (Roman et al. 2001), therefore the permanent plot intervals should be adjusted for the overall area of the marsh to achieve this replication. No permanent plots should be less than 10m apart. Scaling of placement of the plots across the landscape will depend on the scale of the study area. For example, a larger marsh could have permanent plots placed at 20m intervals along each transect with individual transects 50m apart. Alternatively, a smaller creek marsh could have permanent plots placed at 10m intervals, with transects 10m apart. Each permanent plot is then permanently marked with labeled stakes driven into the marsh. The permananent vegetation sampling plots which are one meter on a side (Roman et al. 2001) are offset approximately 1 m from the marking stake perpendicular to the transect line and two diagonal corners of each plot are marked with small stakes. A groundwater well may be established 1 m from the marking stake at 180° from the permanent plot. The capped wells are constructed from schedule 40 PVC extended approximately 50 cm into the marsh surface (after Roman et al. 2001). Other sampling items such as a permanent sediment-erosion table (SET) may be similarly arranged around the sampling location stake.

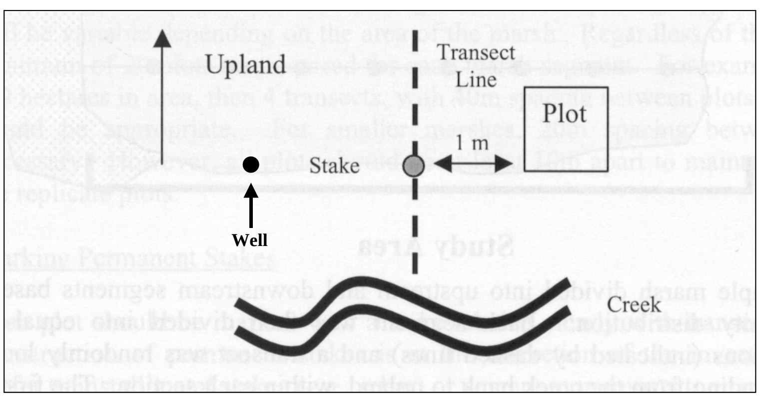

Figure 2. Sampling Plot and Well Orientation
(modified from Roman et al. 2001)

Emergent Vegetation Sampling Methods

Each $1m^2$ vegetation sampling plot is sampled non-destructively for visual estimates of percent cover for each species or cover category (i.e., wrack, bare ground). A variety of plant cover estimates are available. Here a percent cover estimate with 5% intervals is proposed based on a reference cover guide that will be established to assist in standardization. This approach is chosen to permit more rigorous statistical analyses than a non-linear approach will allow. In addition to cover estimates, shoot or stem densities and maximum canopy height is to be determined for each species within each plot. If the vegetation is very dense, then the plot may be sub-sampled. The groundwater well is sampled for salinity/conductivity.

Sampling should be conducted at least during the annual maximum biomass for the marsh plant community in the study area. All sampling should be completed within a two-three week interval, if possible, and should be conducted during low tide to minimize surface water effects. In salt marsh areas this typically period will occur in late summer. In freshwater marshes the plant community may progress through several periods of changing species dominance and sampling may have to be repeated 2-3 times during the growing season (Doumlele 1981; Odum et al. 1984). If the growing season patterns are unknown for the study region, initial monthly sampling should be undertaken during the first year to delineate the seasonal peak(s). Annual sampling should be initially repeated at a 1-2 year intervals and subsequently at 3-5 year intervals depending on the system. If the study area is a restoration or impacted site at a minimum the sampling should be repeated annually until the recovery period or rate of change slows to a pre-determined rate of change or some level of vegetation cover is reached (ie. 100%. More frequent sampling may be conducted depending on the specific research or management question(s) that is/are being investigated.

Submersed Aquatic Vegetation Sampling Design

Beds of SAV are typically found growing along an open shoreline of a bay, lagoon or tidal estuary or river. In most cases the study bed or vegetated area can be considered one segment. Transect placement for a SAV bed is similar to the emergent vegetation transect placement, but they may not necessarily be a continuation of the emergent vegetation transects if there are no adjacent emergent wetlands or only the SAV vegetation is being studied. For the study of SAV beds alone at a particular site, individual transects are located by first dividing each study area into equal sized sections. One or two transects are randomly located within each section so that a total of four or five transects are established across the study area. Each transect should traverse the elevation gradient from the shoreline bank to the deepest edge of the bed. Transects should be located no less than 10m apart to maintain independence and should cover an area that is representative of the section. The determination of “representative sections can be done by use of aerial imagery or if this is not available, visual estimates of cover or SAV abundance from a boat using best professional judgement. The first permanent plot should be located at a random distance off a suitable benchmark on the shoreline (ie. mean low water-MLW). For example, if the unvegetated, subtidal zone is only 3 m wide then the zone is divided into five 60 cm intervals and the first permanent quadrat is randomly located at one of the five intervals. If the unvegetated, subtidal zone is 30 m wide then the first quadrat is located randomly within the first 10 m of the transect. If the subtidal transect is a continuation of the tidal marsh transect then the first plot location should be located off the initial emergent plot. Differences in scale of the width (shallow to deep, or upland to water edge) of the separate communities may necessitate that the sampling plot intervals be different between the emergent and submersed habitats or portions of the transects. As with the emergent community a total of at least 20 plots per submersed bed study area are required for adequate sampling power, therefore the permanent plot intervals should be adjusted for the area of the bed to achieve this sampling replication. No permanent plots should be less than 10m apart. Because the location and depth of outer edge of a SAV bed can have important implications related to environmental conditions affecting bed dynamics, the location and depth of the outer bed edge should be delineated. As SAV abundance may gradually lessen with depth depending on the depth contour, the outer bed edge may have to be estimated. Typically, it is defined as less than 5% cover.

The permanent transects should be fixed by placing permanent PVC poles and/or stakes at intervals along each transect (Figure 2). A minimum of two to three poles and underwater stakes per transect should be established at appropriate intervals depending on the scale of the study area. If poles are not feasible then underwater stakes extending a suitable distance above the sediment surface should be established. In many systems stakes placed 50m to 100m apart and extending 25 cm above the sediment surface are suitable. In large systems, the transects may have to be established and marked using GPS, buoys or other appropriate techniques.

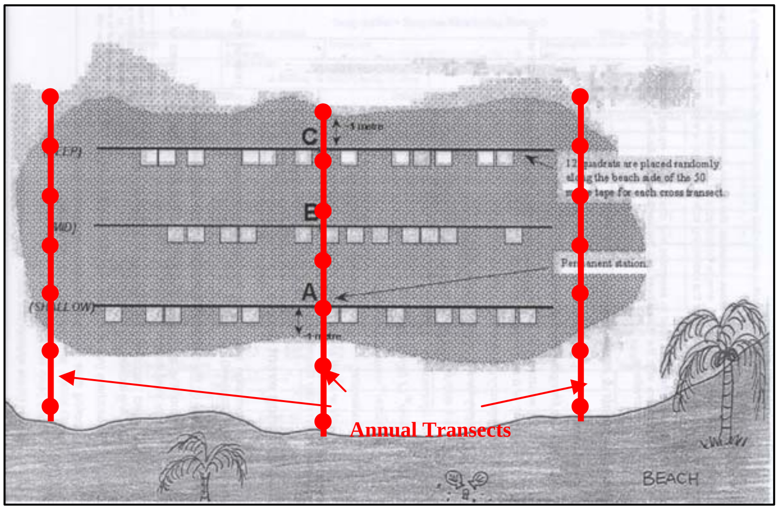

Figure 1. Example of Permanent Transects and SeagrassNet Transects (modified from Short et al. 2002)

Each permanent sampling plot is offset approximately 1m from each individual plot location along the transect. The sampling plots are located by stretching a 100m or longer plastic or fiberglass measuring tape or non-stretching line between the transect poles. If permanent poles cannot be established then temporary poles of PVC or other locally available material are established for the duration of the sampling.

Each plot is sampled non-destructively for percent cover by each species or cover category (e.g., bare ground, detritus) within a 0.25 m^2 area. (Note: SAV clonal patchiness may require a much larger sampling area than $0.25m^2$). In addition to cover estimates, shoot or stem density and maximum canopy height should be determined for each species within each plot. If the vegetation is very dense then the plot may be sub-sampled for density, height and leaf or shoot width as appropriate for the community (van Tussenbroek 1996; Short 1983; Phillips 1983). An area reserved for sampling other factors such as sediment nutrients, pore water sulfide, sediment deposition, etc. should be located at a 1m fixed distance from the transect line point oriented 180° from the vegetation sampling plot. Voucher specimens including flowers, fruits and belowground material of each species and their various morphological variants should be sampled and appropriately preserved.

Submersed Aquatic Vegetation Transect Sampling Methods

Sampling should be conducted during at least the annual maximum biomass for the SAV species in the study area. All sampling should be completed within a two-three week interval if possible. In many seagrass areas this typically will occur from early to mid summer. In freshwater SAV areas this period may occur in late summer or early fall (Moore et al. 2000). In mixed species SAV communities such as those in the lower Chesapeake Bay (Orth and Moore 1986) there may be seasonal dominance of one species (*Z. marina*) in early summer and another (*R. maritima*) in the late summer and two samplings may be required. If the growing season patterns are unknown for the region of interest, initial monthly sampling may be required to delineate the season peak(s). Since SAV can be subject to significant year-to-year variability in abundance, annual sampling should be conducted. If the study area is found to be consistently stable then monitoring intervals can be extended to 2-3 years or more. More frequent sampling (annually or monthly) may be conducted as required to evaluate the level of SAV abundance changes required for a particular study.

Complimentary SeagrassNet Based Sampling

SeagrassNet is a global monitoring program developed to investigate and document the status of seagrass and SAV resources worldwide. The SeagrassNet protocol (Short et al. 2002) may be considered as an optional additional component of NERRS submersed vegetation monitoring. This specific approach will provide additional detailed, complementary information relative to the structure of the vegetation communities at shallow-edge, mid-bed and deep-edge areas. In addition, it permits detailed comparisons of the status and trends of submersed vegetation communities in the NERRS reserves with that of other groups studying long term trends in seagrass and other SAV communities world-wide. The SeagrassNet program started with a pilot study in seven countries of the Western Pacific in 2001 and is now expanding to other countries in North America, Europe and Africa. Its purpose is to develop a network of intensive monitoring sites linked via the World Wide Web by an interactive database (www.seagrassnet.org). The monitoring component consists of a science oriented monitoring program that is based on specific standardized monitoring protocols (Short et al. 2002*)*. The general approach of this detailed monitoring protocol is to establish three, permanent, 50-m wide, cross-transects that are oriented parallel to the shoreline near the inner edge, middle and outer edge of the SAV bed. The center of the transects would be located along a perpendicular transect located as described (Figure 2) in the NERRS SAV monitoring protocol.

The SeagrassNet sampling is generally repeated quarterly (every three months). Two weeks prior to each sampling a Hobo® (Model 8-004-02; Micro*DAQ*.com, Ltd) light logger or comparable remote monitor is deployed at the midpoint of each of the three cross-transects, and an additional logger is placed on shore above the high tide elevation. Six quadrates are located randomly along the 25 m cross-transects to the left and right of the centerline. Sampling of each 0.25m^2 quadrat consists of: vertical photographs using disposable cameras; visual % cover; water depth and local time; canopy height for dominant species; evidence of grazing recorded; flower and fruit counts. A biomass core is sampled 0.5m adjacent to the quadrat. The vegetation is separated into leaves, sheaths and stems, and belowground material. The shoots are counted by species. Dry weights are then determined on all components. Triplicate, small (20 cc syringe) sediment cores are sampled from the mid-point of each cross-transect for organic content and grain size (Short and Coles 2001). The distance to channelward seagrass edge (continuous meadow) and distance to last shoot (most offshore) and distance from the shore to the shallowest edge is measured to evaluate any bed migration. Voucher specimens of each species identified including shoots, flowers and fruits (if available) and belowground material should be collected and appropriately preserved. Duplicate specimens would be sent to SeagrassNet where they are currently housed in a special collection at the Smithsonian Institution.

Currently individual SeagrassNet participants send all voucher specimens, field photographs and field data to the Jackson Estuarine Lab for data summarization, further sample processing, QA/QC and archiving. Field data are entered directly into the web. All other processing is done locally. For NERRS, one reserve could serve the archival function as well as serving as the focus of the interactive database. Data QA/QC would be done locally and then sent directly to CDMO for archiving and in a manner similar to the current nutrient monitoring data.

Data Analyses

Repeated measures analyses or other parametric approaches are typically used to evaluate changes in plant metrics over time and among sites. Non-parametric statistical tests can be used to evaluate similarities of vegetation communities between sites or over time (Roman et al. 2001). Ordination techniques and similarity indices as well as regression techniques can also be used to develop hypotheses relative to community structure or relationships between vegetation and other environmental factors.

Science Implications

This NERRS sampling protocol is based upon established, peer reviewed and published protocols and is consistent with other ongoing emergent and submersed monitoring programs. The spatial design and sampling intensity is appropriate for long term monitoring where the objective is to compare specific study areas over time. Some specific questions that can be tested may be related to: What is the change in non-impacted habitat, degraded or recovering habitat over time? How do specific impacted and unimpacted emergent and submersed vegetation in reserve specific area of interest compare? What is the effect of invasive species on the plant community? What factors are related to observed vegetation changes? How is global climate change and relative sea level rise affecting representative vegetation areas in the reserves? Are any changes in vegetation communities among the specific study areas within the NERRS consistent?

Management Implications for NERRS

Quantification of habitat changes both within and among the reserves in the reserve system is an important NERRS goal. In addition, the developing strategy and framework for NERRS restoration efforts requires consistent, “Scientifically-based” monitoring studies that can be applied similarly to natural, impacted and restored sites, so that the effectiveness of habitat restoration and well as quantification of cause and effect relationships can be measured. Additionally, accurate evaluation of change in coastal vegetation systems at the national and international level requires that consistent methodologies be applied so that any broad trends can be more clearly determined. Evaluating patterns of non-native and invasive species expansion across broad regions also requires a consistency of approach. The emergent and submersed vegetation monitoring approach proposed here will address these and other management objectives.

Literature Cited

Brush, G.S. 2001. natural and anthropogenic changes in Chesapeake Bay during the last 1000 years. Hum. Ecol. Risk Assess. 7: 1283-1296

Dahl, T.E. 1990. Wetland losses in the United States, 1780s to 1980s. United States Department of the Interior, Fish. and Wildlife Service, Washington, DC. 21 pp.

Davis, R.A. and M. Andronaco. 1987. Impact of hurricanes on Pinellas county, Florida, 1985.Sea Grant Report, University of south florida. Gainesville, Fl. 53 pp.

Doumlele, D.G. 1981. Primary production and seasonal aspects of emergent plants in a tidal freshwater marsh. Estuaries 4: 139-142.

Kemp, W.M., R.R. Twilley, J.C. Stevenson, W.R. Boynton, and J.C. Means. 1983. The decline of submerged vascular plants in upper Chesapeake Bay: Summary of results concerning possible causes. Mar. Technol. Soc. J. 17: 78-89.

Moore, K.A., J.L. Goodman, J.C. Stevenson, L. Murray and K. Sundberg. 1995. Chesapeake Bay nutrients, light and SAV: relations between variable water quality and SAV in Field and mesocosm studies. Final Report. CB003909-02. EPA Chesapeake Bay Program, Annapolis, MD. 106pp.

Moore, K.A., D.L. Wilcox, and R.J. Orth. 2000. Analysis of abundance of submersed aquatic vegetation communities in the Chesapeake Bay. Estuaries 23: 115-127.

Neckles, H.A. and M. Dionne (eds.) 2001. Regional standards to identify and evaluate tidal wetland restoration in the Gulf of maine. Wells National Estuarine Research Reserve Technical Report, Wells, Maine. 21pp.

Neckles, H.A., M. Dionne, D.M. Burdick, C.T. Roman, R. Buchsbaum and E. Hutchins. 2002. A monitoring protocol to assess tidal restoration of salt marshes on local and regional scales. Res. Ecology 10: 556-563.

Niering, W.S. and R.S. Warren. 1980. Vegetation patterns and processes in New England salt marshes. BioScience 30: 301-307.

NOAA/NOS. 1999. national Ocean Service Stategic Plan, 1999-2004. NOAA/National Ocean Service. Silver spring, MD.

Odum, W.E., T.J. Smith, J.K. Hoover and C.C. McIvor. 1984. Ecology of tidal freshwater marshes of the United States east coast: A community profile. Biol Serv. Program, Fish. Wildl. Serv. 190 pp.

Orth, R.J. and K. A. Moore. 1983. Chesapeake Bay: an unprecedented decline in submerged aquatic vegetation. Science 22: 51-52.

Orth, R.J.and K.A.Moore. 1986. Seasonal and year-to-year variations in the growth of of Zostera marina L.(eelgrass) in the lower Chesapeake Bay. Aquat. Bot., 24:335-341.

Perry, J.E. and R.B. Atkinson. 1997. Plant diversity along a salinity gradient of four marshes on the York and Pamunkey Rivers in Virginia. Castanea 62: 112-118.

Perry, J.E. and C.H. Hershner 1999. Temporal changes in the vegetation pattern in a tidal freshwater marsh. Wetlands 19: 90-99.

Phillips, R.C. and R.L. Lewis III. 1983. Evidence of environmental gradients on variations in leaf widths and transplant success in North American seagrasses. Mar. Technol. Soc. J. 17: 59-68.

Sandlund, O.T., P.J. Schei and A. Viken (eds.) 1999. Invasive species and biodiversity management. Kluwer Academic, Boston, MA. 431 pp.

Short, F.T. 1983. The seagrass, Zostera marina L.: Plant morphology and bed structure in relation to sediment ammonium in Izembek lagoon, Alaska. Aquat. Bot. 16: 149-161.

Short, F.T. and R.G. Coles (eds.) 2001. global Seagrass Research Methods. Elsevier Science B.V., Amsterdam, 473 pp.

Short, F.T, L.J. McKenzie, R.G. Coles and K.P. Vidler. 2002. SeagrassNet Manual for Scientific Monitoring of Seagrass Habitat. University of New Hampshire. 55 pp

Short, F.T. and S. Wyllie-Echeverria. 1996. natural and human-induced disturbance of seagrasses. Environ. Cons. 23: 17-27.

Short, F.T. and H.A. Neckles. 1999. The effects of global climate change on seagrasses. Aquat. Bot. 63: 169-196.

Roman, C.T., W.A. Niering, R.S. Warren. 1984. Salt marsh vegetation change in response to tidal restriction. Environ. Management 8: 141-150.

Roman, C.T., J.A. Peck, J.R. Allen, J.W. King, P.G. Appleby. 1997. Accretion of a New England (USA) salt marsh in response to inlet migration, storms, and sea-level rise. Est. Coast. And Shelf Sci. 45: 717-727.

Roman, C.T., M.J. Janes-Piri and J.F. Heltshe. 2001. Monitoring salt marsh vegetation. Long-term Coastal Ecosystem Monitoring Program, Cape Cod national Seashore, Wellfleet, MA. 47 pp.

van Tussenbroek, B.I. 1996. Leaf dimensions of transplants of *Thalassia testudinum* in a Mexican Caribbean reef lagoon. Aquat. Bot. 55: 133-138.

Warren, R.S. and W.A. Niering. 1993. Vegetation change on a northeast tidal marsh: interaction of sea-level rise and marsh accretion. Ecology 74: 96-103.

Watson, R.T., M.C. Zinyowera, R.H. Moss. 1996. Climate change 1995 – Impacts, adaptations, and mitigation of climate change: Scientific-technical analysis. Contribution of working group II to the Second Assessment Report of the Intergovernmental panel on climate Change. Cambridge University Press, NY. 878 pp.