Development and Implementation of an Integrated Monitoring and Assessment Program for Tidal Wetlands

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These studies were initiated and overseen by Dr. Danielle Kreeger, science director at the Partnership for the Delaware Estuary (PDE) who served as principal investigator for the project. Angela Padeletti, PDE science coordinator, served as general project manager as well as leader for the rapid assessments. Dr. Tracy Quirk of the Academy of Natural Sciences of Drexel University (ANS) served as co-principal investigator and leader for site-specific station monitoring. Angela Padeletti led quality assurance and quality control elements. The Partnership wishes to express sincere appreciation to Dr. David Velinsky, Mr. Roger Thomas (ANS), and Dr. David Bushek (Rutgers University) for their technical support, boat support, and scientific advice throughout the project. Appreciation is also extended to Kelly Somers, Laura Whalen, William Whalon, Viktoria Unger, Michelle Brannin, Paula Zelanko, Paul Kiry, Mike Schafer, Kurt Cheng, Linda Zaoudeh, Paul Overbeck, Martha-Maxwell-Doyle, David Keller, Dr. David Bushek. who provided primary field support and GIS assistance. Individuals that helped provide advice with permitting include Dorina Frizzera (NJ Coastal Programs) and Thomas Belton (NJ Department of Environmental Protection). Finally, we are also grateful to the USFWS for providing use of an airboat for the Tinicum station installation.

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Established in 1996, the Partnership for the Delaware Estuary is a non-profit organization based in Wilmington, Delaware. The Partnership manages the Delaware Estuary Program, one of 28 estuaries recognized by the U.S. Congress for its national significance under the Clean Water Act. PDE is the only tri-state, multi-agency National Estuary Program in the country. In collaboration with a broad spectrum of governmental agencies, non-profit corporations, businesses, and citizens, the Partnership works to implement the Delaware Estuary's Comprehensive Conservation Management Plan to restore and protect the natural and economic resources of the Delaware Estuary and its tributaries.

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Note that data collected through this project is available on the Final Report CD's and can be provided again upon request

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Introduction

Coastal wetlands are a hallmark feature of the Delaware Estuary and are critically important for both ecosystem and human health. A scarcity of monitoring data, however, hampers efforts to regulate and preserve these wetlands even as they appear to be undergoing rapid loss and continued degradation. The Delaware Estuary has the largest freshwater tidal prism of any estuary in the world, and the resulting broad salinity gradient allows for nationally rare freshwater tidal wetlands in the upper estuary, along with brackish and salt marshes in the middle and lower estuary. Together, these different marsh types form a nearly continuous fringe around the perimeter of the tidal Delaware system (PDE, 2006, Figure 1).

The ecological and economic services that are directly or indirectly furnished by tidal marshes are a myriad: flood protection, nursery, forage and nesting habitats for fish and wildlife; water quality improvement, carbon and nutrient sequestration. Sitting at the nexus between the land and the sea, tidal wetlands are in the coastal hazard area where they are subject to considerable direct anthropogenic alteration (e.g. development, dikes, bulkheads, mosquito ditching, and roads).

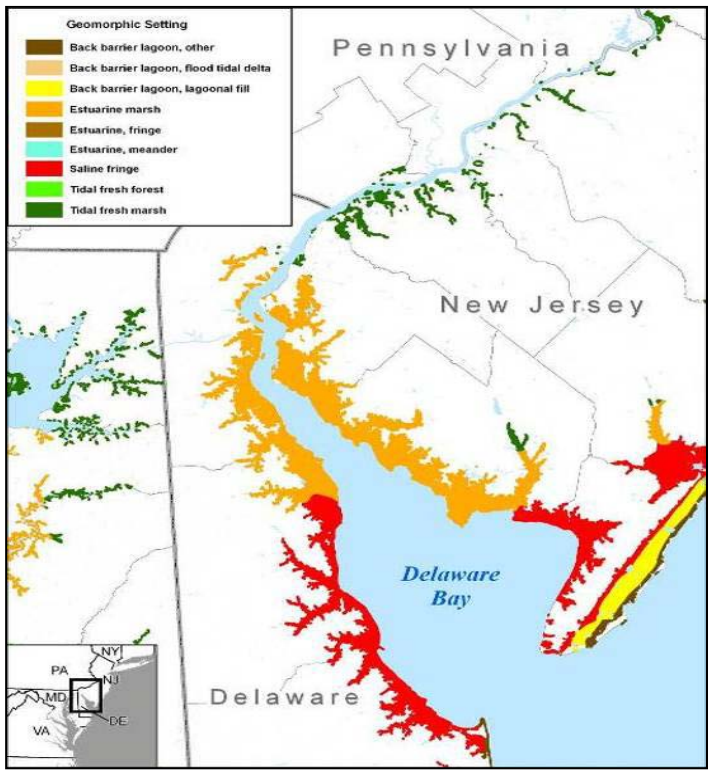

Figure 1. Tidal wetlands of the Delaware Estuary (Reed et al. 2007).

Despite their importance at the ecosystem scale, the environmental integrity of the tidal marshes of the Delaware Estuary is difficult to presently assess. What limited data are available suggests that these wetlands continue to be lost and threatened by continued development and conversion, degradation, sea level rise, sudden marsh dieback and a host of other factors. We continue to lose acreage (PDE 2008, 2012), and perhaps just as importantly, more than half of the marshes are believed to be in a degraded state (Kearney et al. 2002). Satellite imagery trends analysis shows that more than 2% of the >140,000 acres of tidal marsh were lost from the Delaware Estuary between 1996 and 2006 (PDE 2012). Future projections using SLAMM v6 modeling suggests that 25-75% of our coastal wetlands will be lost with a 1 m rise in sea level. Clearly, the continuing losses of acreage and declining condition point to a major concern for the natural wetland-dominated, muddy Delaware Estuary, which is under imminent threat from landscape and climate change.

Until recently there was no regular, coordinated and consistent means to assess tidal wetland condition across the watershed, hampering efforts to track ecosystem health and manage the system holistically, because each state assesses coastal wetlands differently. The inconsistent and patchy data for wetland extent and health also thwarts decision-making by coastal managers who are pressed to choose where and how to invest to protect and enhance long-term wetland "natural capital." Monitoring wetland condition is just as important as monitoring extent because reduced health is usually a precursor of acreage loss, often occurring en masse during punctuated disturbances such as storms. Poorly functioning marshes are also prone to invasive species and are not as valuable for fish and wildlife. Restoration and protection efforts would be more strategic and effective with better information on how and where marsh condition might be improved to boost resilience and safeguard against further acreage losses.

Because of the renowned importance of tidal wetlands to the health of the Delaware Estuary and to residents of the watershed, over the past 5+ years the science and management community of the Delaware River Basin has elevated tidal wetland condition and extent as a top priority for monitoring, considering these habitats as one of the leading indicators for environmental conditions in the basin as a whole (PDE 2008, 2012.) The White Paper on the Status and Needs of Science in the Delaware Estuary (Kreeger et al. 2006,) stressed the need to develop a better understanding of tidal wetland status and trends. The paper identified this concern as the second most important "top ten" technical need for the entire basin, second only to contaminant issues. In 2006-2007 the Partnership developed a wetland strategy to fill vital data gaps (see below). The strategy, which included tidal wetland assessment, protection and research, was then included as a core component of the 2007 PDE Strategic Plan (PDE, 2007). In the time since then, PDE has worked with diverse partners to begin to implement the wetland strategy, which is now being updated and strengthened in 2012.

The 2007 PDE wetland strategy consisted of a collaborative effort among PDE staff, state and federal agency representatives, and academics from the region. A 4-tier monitoring and assessment program was envisioned that would provide rigorous, comparable data across all of the diverse and abundant tidal wetlands of the Delaware Estuary. The strategy helped PDE prepare funding applications, and the resulting program was named the Delaware Estuary Wetland Monitoring and Assessment Program (DEWMAP). With recent expansion to neighboring estuaries such as Barnegat Bay, NJ, DEWMAP has now been renamed to be the Mid-Atlantic Coastal Wetland Assessment (MACWA). The strategy of MACWA follows EPA national guidance (U.S. EPA, 2001, Oct 28) for a 4-tier approach:

- Tier 1: landscape census surveys of extent and condition (being performed through other efforts in collaboration with PDE, with partial support from the Pennsylvania Coastal Zone Program),
- Tier 2: probabilistic sampling on-the-ground across the study region to assess condition and ground-truth Tier 1 surveys (i.e., the focus of the present study),
- Tier 3: intensive studies to examine relationships among condition, function, and stressor impacts (studies are being performed by PDE and partners),

- Tier 4: intensive monitoring of condition and function at smaller number of fixed stations (being performed by PDE with partners, launched with this grant)

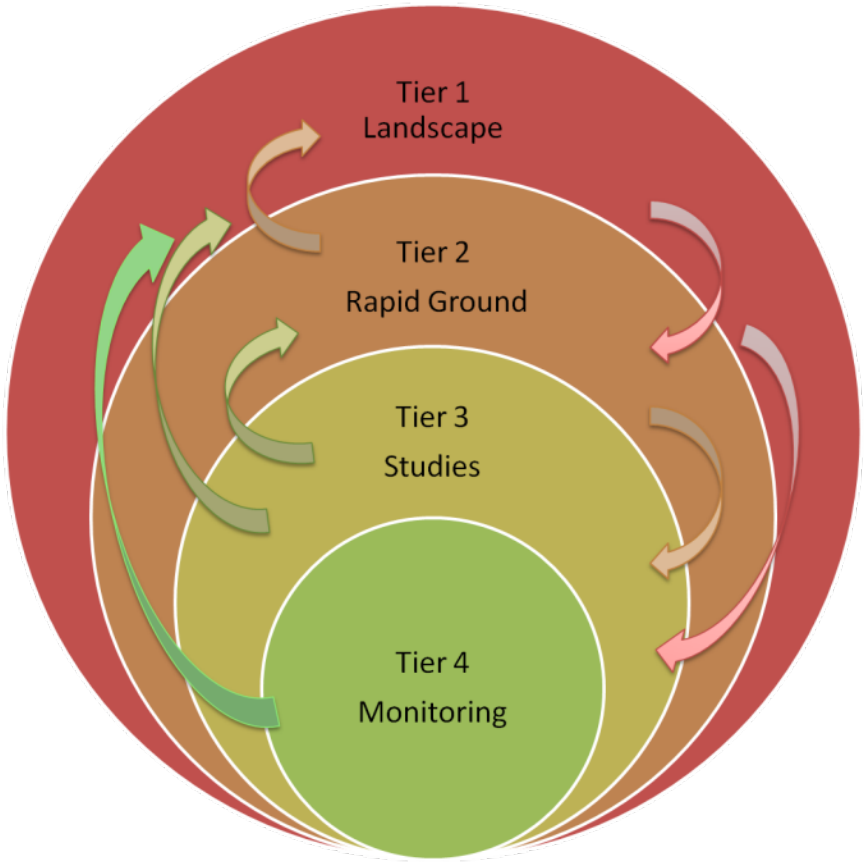

Figure 2: Four tier wetlands strategy.

Development and Testing of Rapid Assessment Methods (RAM).

A core component of this program is Rapid Assessment Methods (RAM) that is used to quantify the condition of wetlands (Tier 2 in the design, see above). Tier 2 assessments are critical to ground-truth and link Tier 1 census data to Tiers 3 and 4 (intensive studies and monitoring). Both Delaware and Pennsylvania had been working on such methods, but not from the perspective of the whole watershed with a goal to facilitate inter-comparability among wetland types and states across the system. Coastal (tidal) wetlands were also not the main focus of state RAM efforts.

Probabilistic surveys using RAM protocols have been increasingly used across the United States. In 2011, they were the focus of the National Wetland Condition Assessment, the first comprehensive nationwide assessment of wetland condition (US EPA, 2011). Unfortunately, the national sample density was sparse for coastal wetlands because it encompassed all wetlands, both tidal and non-tidal. Few study locations were planned within the tidal wetlands of

Delaware Estuary, and none in Pennsylvania's tidal wetlands within the Delaware Estuary. (U.S. EPA, 2011)

Within the Delaware Estuary, the State of Delaware has been the leader in developing RAM protocols (DNREC, 2010 and Jacobs, 2010), including both tidal and non-tidal wetlands. Two RAM protocols were developed to capture the difference of vegetation, fauna, geomorphology, and other factors. For example, freshwater tidal marshes of the Delaware Estuary are subject to a much wider tidal range (up to 9 feet) compared to salt marshes lower in the system (less than 3 feet), which conveys different attributes regarding sediment supply and chemistry. Salt marshes, being micro tidal, are expected to be more prone to impacts associated with sea level rise, whereas, freshwater tidal marshes are threatened with salinity rise. Layered on top of their physical differences, the context and human impacts are also in stark difference. Pennsylvania's tidal marshes are situated in the urban river corridor, where they are subject to a multitude of land use and water quality impacts, whereas salt and brackish marshes lower in the system are subject to agricultural practices, snow geese grazing disturbances, etc. For the present study, PDE adapted the Delaware protocol so that it would be useful for assessing the health of all types of tidal wetlands of the Delaware Estuary.

<u>Installation of Fixed Stations for Site-Specific Intensive Monitoring (SSIM).</u>

The second component of this grant was to devise Tier 4 protocols for fixed station monitoring and to install a set of monitoring stations where these methods would be executed. For Tier 4 work, we worked with the states and academic partners to establish stations in areas spanning different tidal wetland types along the salinity gradient. These stations also served as text sites for the on-the-ground rapid assessment methods (Tier 2). In addition to devising new methods for Tiers 2 and 4, and installing fixed monitoring stations, additional outcomes from this study included new data on current tidal wetland condition (results of Tier 2 testing), and site-specific variation in some important wetland features and functions (first year of Tier 4 monitoring). Hereafter in this report, we refer to Tier 2 rapid assessment methods as "**RAM**" and Tier 4 site-specific intensive monitoring as "**SSIM**"

Monitoring stations for SSIM were selected covering a range of marsh types, conditions, and in different health states. Monitoring for geomorphology, biota, and water quality was designed to describe both structural and functional properties and overall integrity. Three SSIM stations were installed for this pilot study: a salt marsh in New Jersey, brackish marsh in Delaware, and a freshwater tidal marsh in Pennsylvania. Reference stations were selected using best judgment by the MACWA Workgroup, which was also created for this project as a technical advisory body that was affiliated with the PDE Science and Technical Advisory Committee (STAC). All of these SSIM stations are subject to potential shifts in base forcing functions of the estuary such as sea level rise, sediment budgets, temperature. There was, however, considerable variation among SSIM stations in local stressors (e.g. nutrient loadings, mosquito ditch practices, impoundments) (Somers 2011).

Fixed reference stations were sampled with intensive measurements of tidal wetland function and condition as well as an array of environmental parameters. In Year 1, the stations were selected and installed, and intensive monitoring proceeded through the balance of Year 2. Monitoring consisted of a variety of biological, chemical and physical parameters and metrics; Although there are many parameters and metrics that could be included in the "ideal" monitoring design, in this study we selected a subset of "core" measurements to maximize outcomes relative to cost and feasibility. Principal core metrics include biological integrity and biomass, and surface elevations and physical conditions (see below). Given the emerging concern over whether coastal wetlands can keep pace with sea level rise, we strengthened our original station design for physical conditions (e.g. by installing 3 instead of 1 surface elevation table for station). To compensate, we altered our sampling protocol for water quality by foregoing installation of water monitoring equipment and instead sample water quality when in the field. Since we are uncertain whether funding will be available to sustain monitoring at our fixed stations, this reprioritization of sampling metrics will allow us to be more flexible with monitoring frequency in the future, depending on funding.

To appropriately cover the different types of coastal wetlands and large geographic area, our long-range plan is to install and monitor 6 fixed stations in the Delaware Estuary (2 in Delaware, 1 in Pennsylvania, 3 in New Jersey). This study covered installation and baseline monitoring of core metrics for the first three of these stations: Christina in Delaware, Tinicum in Pennsylvania, and Maurice in New Jersey. Each station consisted of a set of three permanently marked study plots, each within a vegetated area containing a surface elevation table (SET). The three SETs per station were situated along an axis from upper to lower tributary (i.e. nearer to further from the main estuary) and also at increasing distances from the marsh edge (e.g., 100, 200, 400 m from main tributary).

The condition of vegetation on the high marsh and adjacent intertidal edge was also assessed along permanent transects (at least one per SET, at least 3 per station), which allowed repeated analyses of marsh biological and physical conditions along the landward-seaward axis. Transects extended from the permanent SET plot toward the tidal waterway.

<u>Partnering, Peer Review and Project Management.</u>

This project's main objective was to establish within the Delaware Estuary a multi-tiered wetlands assessment strategy and to begin to implement it. The Partnership for the Delaware Estuary (PDE) held many conference calls and meetings with partners from the region and also experts throughout the country to devise the most productive RAM and SSIM plan, as well as a long-term strategy for expansion for the Delaware Estuary and beyond. The Mid-Atlantic Coastal Wetlands Assessment (MACWA) work group was formed as an expanded technical body to provide peer review, and which included representatives from the states of New Jersey, Pennsylvania and Delaware, EPA, Villanova University, and the Academy of Natural Sciences of Drexel. Pulling from already established protocols from organizations like U.S. Fish and Wildlife Service, U.S. Geological Service and states within and outside the region the MACWA group slowly worked through various options for monitoring protocols and methods, selecting those which the group felt would yield maximal scientific outcomes. These protocols that were developed have now been replicated by many others throughout the Delaware Estuary, Barnegat Bay, NJ, and New York City Parks. Preliminary baseline monitoring results from the 2010-2011 seasons are reported below.

Since coastal wetlands are a hallmark feature of large Mid-Atlantic estuaries where they furnish critical benefits that sustain coastal lives and livelihoods, we believe it is vitally important to sustain and grow the monitoring and assessment programs established with this grant. Through partnering with states as well as academia in the region, we hope to sustain the effort and thereby provide valuable information to guide coastal decision makers who must wisely use precious restoration funding and balance best management practices for coastal habitats.

Sites with Differing Histories

Three marshes were selected for RAM and SSIM study sites. These were chosen because they were regarded as representative of the sampling frame for coastal marshes throughout the Delaware Estuary;

1) *Tinicum Marsh*. A freshwater tidal marsh located just south of Philadelphia, PA.
2) *Maruice River Marsh*. A salt marsh located along one of the larger rivers in southern New Jersey.
3) *Christina March*. A freshwater tidal marsh located on the Christina River, DE, just south of the city of Wilmington.

In addition to having different marsh ecologies because of prevailing salinity differences, these sites also have different anthropogenic stressors, tidal amplitudes, sediment supplies, etc. Rather than targeting the best condition marshes for use as reference sites, we chose sites tat were regarded as indicative of general (but diverse) conditions that are likely to be encountered more commonly. If funding permits, we would like to strengthen future MACWA activities by including reference locations.

Tinicum

Dutch, Swedish and English colonists started to settle in the area of what is now Philadelphia in the early 17th century. The city of Philadelphia was quickly established in 1682 and grew rapidly to become the largest city with the most active port in the 13 colonies by the 1750s. During this time, the area to the south of the city was covered by tidal marshes (Fig 3), and the area south of the Schuylkill was commonly referred to as "The Neck". This area, according to the Philadelphia Water Department, once encompassed thousands of acres of tidal marsh (Philadelphia Water Department).

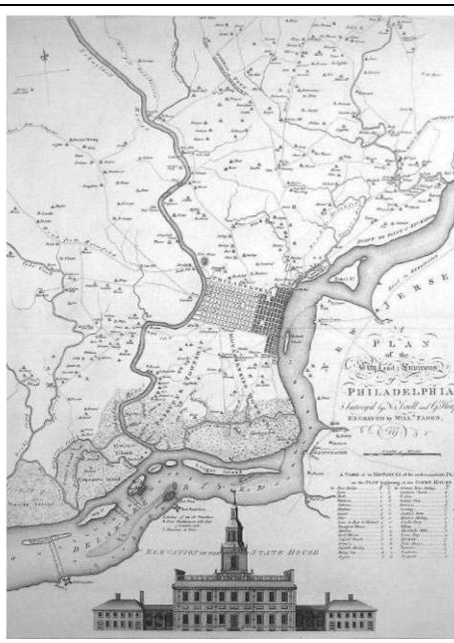

Figure 3. 1777 map of wetlands in southern Philadelphia region.

Also according to the Philadelphia Water Department, by the 1800's The Neck had approximately six square miles of new neighborhoods that were surrounded by wetlands that had both natural tidal creeks and man-made drainage canals. At about the same time, miles of dikes were built along both the Delaware and Schuylkill, allowing the inhabitants to convert wetlands for growing crops, a practice that extended into the 20th century. In the early 20th century, alterations to the marsh continued with millions of cubic yards of fill brought in to raise these lowlands. The process of filling the marsh continued for 50 years with city refuse, dredge spoils and excavated material from a subway being only some of the material used.

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In an article entitled "A Day in the Ma'sh" by Maurice F. Egan (1881), the author explains the agricultural processes going on in the marshes and other anthropogenic impacts taking place in the marsh. "…The Neck stretches below the city proper… To the east, along the Delaware, is the Ma'sh The land is low, and high dikes, or banks, prevent the aggressions of the Delaware. These banks are fringed with wide spaces of bending reeds. The Neck shows many signs of modern improvement . Oil-refineries are not unknown, and in many places whole plantations of the primeval Jamestown-weed have been destroyed by the loads of refuse from the soap-factories that have been cast upon them. But even the evidences of encroaching civilization assume a picturesque aspect in this mural yet rural territory."

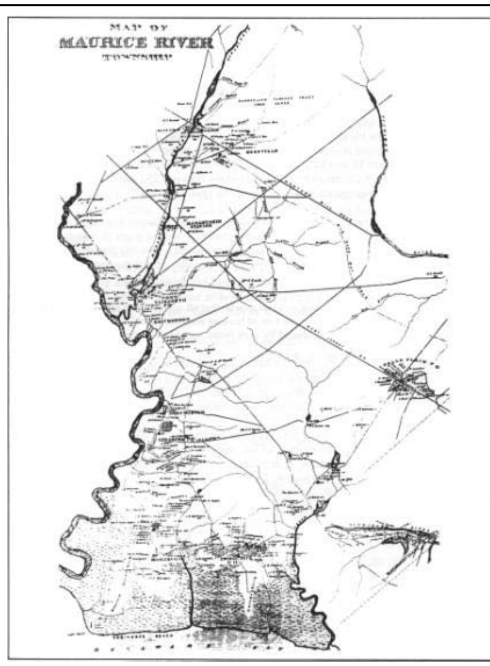

Figure 4. Map of Maurice River Township (Atlas, 1876).

Development in the region continued at breakneck speed, with wetlands being filled and drained, taking what was once likely tens of thousands of acres of rare freshwater tidal wetlands during pre-European times to just over 1,000 acres by the 1950's. In 1955 the Gulf Oil Corporation donated 145 acres of the marsh as a preserve that in the 1990's became the federally held John Heinz National Wildlife Refuge at Tinicum (U.S. Fish & Wildlife Service, 2011). The refuge consists of 1,200 acres of which 200 acres comprise the largest remaining tract of tidal freshwater wetlands in Pennsylvania. This preserve is unique in that it is the last large pocket of natural lands in the urban area, located less tan one mile from a large international airport and bordered by Interstate 95.

Therefore, the once vast tidal freshwater marshes of

Pennsylvania have today been nearly eradicated from the landscape, amounting to 200 acres in a federal refuge, and small parcels along the Delaware River upstream to Morrisville. The wetlands or "ma'shs" have been diked, filled, drained and contaminated throughout the last 350 plus years. It is difficult to quantify exactly how many acres still remain because the most recent rigorous assessment by the USFWS National Wetlands Inventory was completed in the 1970's for many parts of southeast Pennsylvania (Kreeger and Homsey, 2012). Despite national policies to achieve "no net loss" of wetlands, losses of coastal wetlands in Pennsylvania appear to be continuing. Based on NOAA land cover data, PDE estimates that about 50 acres of freshwater tidal wetlands were lost in Pennsylvania during the period, 1996-2006 (Kreeger and Homsey, 2012). Currently, there are probably less than 300 acres of vegetated tidal marsh left in Pennsylvania, and PDE has highlighted updating of NWI data for Pennsylvania as a strategic priority for the National Estuary Program (Tier 1 of MACWA). What has been unclear is whether these recent losses have occurred because of direct conversion, declining health, or other stressors. The RAM component of this project sought to characterize the health of the remaining tidal wetlands at Tinicum as a necessary first step in determining causes of decline and potential remediation methods in the future. The SSIM station was installed to facilitate an understanding of functional processes at Tinicum and to provide a baseline for future monitoring there.

Maurice

The Maurice River has a long and rich history as home of the second nationally strategic port in the Delaware River Basin (Philadelphia being the other). The river drains a large area of southwestern New Jersey where agriculture, shipbuilding, and shellfish and finfish industries remain important today. Port Norris, which is located on the lower Maurice, was known as the oyster capital of the world at one point and it still is home to a vibrant oyster and blue crab fishery. The Maurice is the second longest and largest direct tributary to Delaware Bay and also drains parts of the coastal plains of the Pine Barrens. The river flows fifty-eight miles from Gloucester County to Bay. Near the city of Millville, the river is impounded creating Union Lake reservoir, and hence tidal conditions and navigation begin just south of the lake. The entire Maurice runs through five municipalities.

Coastal wetlands of the Maurice are diverse, ranging from salt marshes toward the Delaware Bay and freshwater tidal marshes in upper reaches. The freshwater tidal marshes of the river provide habitat for the largest stand of wild rice in the state, and the Maurice includes habitat for 53% of the endangered species in the state. The river is also part of the Atlantic flyway, providing habitat for innumerable amount of migrating shorebirds, waterfowl and raptors. In 1993 the federal government designated a portion of the river as Wild and Scenic.

The oystering industry started in the 1700's and exploded in the 1800's. The Maurice River became home to hundreds of watermen's boats as well as shucking houses. Oysters were collected from the New Jersey waters just off of the Maurice River and shipped by rail to cities such as New York and Philadelphia. Oysters were harvested not only for a food source but for their shells used to lime the many farm lands in southern New Jersey. In the late 1900's a thriving menhaden fishery developed with the fish being mainly used for animal feed and fertilizer. By 1917, the oyster industry alone brought over ten million dollars a year to the region.

In both the eighteenth and nineteenth centuries, marshes along the Maurice River were converted or "reclaimed" for salt hay farming. Salt hay was used as forage and packing material, and even today it’s regarded as an excellent mulch. Reclaiming marshes for agricultural purposes was not anything new, since the English and Dutch had a long tradition of converting these wetlands for agriculture. Reclamation involved diking and filling, leading to hydrologic alteration and restriction of tidal exchange. In some cases, marshes were also dyked to create freshwater impoundments for waterfowl hunting. This hydrologic alteration lead to a change in dominant plants and a shift in communities found on the marsh platform. According to Nesbit (1885), dikes and creek banks in the area were approximately four feet above the meadow surface, eight feet wide at their bottom, and three feet across the top (Nesbit, 1885). In an 1866 report it was determined that 20,000 acres of lands had been reclaimed, mostly in Cumberland and Salem counties (Sebold, 1992). Cumberland county boarders the west banks of the Maurice River.

As often happens along rivers, industries developed many of the immediate shorelines of the navigable Maurice River as well. Glassmaking, forges, and ship building were among the largest industries found along the river. The combined effects of industry, agricultural runoff, and municipal runoff as left an indelible mark on the waterway, and the Maurice River is listed in New Jersey's 303 (d) list of impaired waters. The river is listed for arsenic, dissolved oxygen, PCB's, mercury and *Enterococcus*. The river is also a major source of nutrient runoff to te Delaware Estuary. Although the Maurice River is not as vibrant as it once was and today many towns are in decline, the watershed still an economic center for southern New Jersey.

Christina

The Christina River drains parts of Delaware, Pennsylvania and Maryland, flowing 35 miles to where it empties into the Delaware River at Wilmington, Delaware. The river and its tributaries drain approximately 565 square miles with the Brandywine Creek draining 58% of this area. The basin provides drinking water to half a million people in all three states.

The Swedes settled in the area in 1638 and immediately started to alter the landscape. In New Castle County, Delaware, by 1885 the Dutch and Swedish had “reclaimed” (converted) 10,000 out of 15,000 acres of marsh (Sebold, 1992). Land was diked and drained to create farm fields near the river, as well as convert "undesirable" lands adjacent to the river to dry lands where industry could be established. Growth of cities such as Wilmington and Newport also helped to degrade and convert the remaining wetlands. Ship yards, rail road depots, and black powder production were some of the major activities along the Christina River.

Among the more famous industries that was founded in the Christina Basin is the DuPont Company. The DuPont Company originated along the Brandywine Creek, providing black powder for the new nation. Later in the 1930's, DuPont expanded its production to include material sciences, such as neoprene, nylon and synthetic rubber. Still later, DuPont manufactured parachutes, powder bags, tires, paint, Mylar, Lycra, Tyvek, Corian and Kevlar. Today, the drainage is home to diverse industries and is home of the largest banana port in the world.

Similar to Tinicum (see above), nationally rare freshwater tidal wetlands were once abundant along the coastal plain of the Christina River, and only remnants of these wetlands remain today. Most of the fringing wetlands that are left are believed to be significantly contaminated or degraded. The Christina contains three federally listed superfund sites and numerous state listed sites. Soil and groundwater is contaminated with toxins as PAHs, arsenic, aluminum, iron and manganese. Wetlands along the Christina were also significantly impacted during construction of Interstate 95 in the 1960's. During the construction the river was re-directed and many wetlands were altered or filled.

Approach and Methods

This project sought to launch the Delaware Estuary Wetland Monitoring and Assessment Program, which was later renamed the Mid-Atlantic Coastal Wetland Assessment after methods were developed that began to be used outside the Delaware Estuary. As a development grant, the major outcomes are new methods, results from testing the methods, and installation of new monitoring stations in representative coastal wetlands. Hence, our methods for the study were to first perform extensive literature reviews and consultations with national and regional wetland experts to ascertain the latest techniques that would be suitable for achieving our goals of designing and implementing Tiers 2 and 4 of MACWA; i.e. rapid assessments and fixed station monitoring, respectively. Secondly, we tested and refined these new methods in the field and compared outcomes to other emerging studies and efforts elsewhere. Finally, we collected baseline data on wetland status, condition and ecological functioning in tidal wetlands of the three study watersheds described above.

The methods that were developed, and the many information sources used to develop them, are described below separately for the two major study components: rapid assessments and site-specific intensive monitoring. Additional details on the actual field methods can be found in the Quality Assurance Project Plan for this study (Appendix A). Results were presented at numerous scientific conferences and are expected to be submitted for publications.

Site Specific Intensive Monitoring (SSIM)

Along the Delaware Estuary, there are approximately 66,978 hectares of tidal wetlands that span a salinity range from freshwater from the head of tides at Trenton, New Jersey to just south of Wilmington, Delaware to brackish marshes that grade into salt marshes towards the mouth of the bay at Lewes, Delaware and Cape May, New Jersey. These coastal wetlands provide important ecological services including nutrient cycling, carbon storage, storm surge protection, natural flood control, and essential habitat for commercially important fish and shellfish. Growing concerns about the potentially increasing rate of relative sea level rise, continued high nutrient loadings, other aspects of climate change, and ongoing coastal development underscore the need for tracking changes in the health, function, and extent of the tidal marshes that fringe the Delaware Estuary. The goal of the site-specific station monitoring (SSIM) was to install the first three stations of a new network of wetland monitoring sites spanning the different states and types of wetlands in the system so that changing wetland conditions and functions can be better understood for guiding sound coastal best management practices. With SSIM, we aim to document changes over time, examine relationships among key variables that underpin wetland-mediated ecosystem services and wetland fates, make predictions about which wetlands are more vulnerable to change (e.g., sea level rise), and then furnish recommendations to managers on how to either sustain these habitats or plan for the consequences of their demise in certain locations.

The Site Specific Intensive Monitoring (SSIM) program within the Mid-Atlantic Coastal Wetland Assessment (MACWA) was piloted by installing stations within each of the three representative tributary wetlands in the Delaware Estuary. An array of physical, chemical, and biological parameters were selected for monitoring that will inform wetland health and document change over time. Baseline monitoring of these SSIM stations was then implemented for up to a two year initial study period. The same three study marshes were targeted for rapid assessment methods testing (see below).

Besides serving as representative marshes for the system, another advantage of choosing these sites was that some existing data had already been collected for marsh surface accretion rates from past coring studies that examined radionuclide activity (Somerfield and Velinsky 2011).. These data suggested that accretion rates averaged over the last 50 to 100 years were approximately two times greater in the tidal fresh water wetlands (0.85 cm/yr) than in the salt marshes (0.52 cm/yr) of Delaware Bay. Two sites were selected for SIMM in the tidal freshwater areas located along the urban corridor of the Delaware River Estuary. In Pennsylvania, the largest tidal freshwater wetland is located in the John Heinz National Wildlife Refuge at Tinicum, and this site was selected as being representative of tidal freshwater wetlands along the urban corridor of the Delaware Estuary. A tidal freshwater wetland along the Christina River in Wilmington, Delaware was also selected for initial SIMM work. For comparison, a salt marsh along the Maurice River, New Jersey was also selected for SIMM.

<u>Selection of SSIM Metrics</u>

Core metrics selected for SSIM were chosen to best strengthen our understanding of how wetlands are changing in response to environmental changes, and how these changes vary spatially and among wetland types. Where possible, data for supplemental metrics were also gathered but cost and capacity limited our ability to monitor all of the core and supplemental metrics that would constitute a fully fledged SSIM design.

The most important stressor to be examined was deemed to be sea level rise. There are many additional metrics that could have been included to further strengthen SSIM and provide information about other anthropogenic stressors (e.g. water quality) that were necessarily limited by cost and capacity. The overriding importance of relative sea level rise is based on many studies that suggest that the Mid-Atlantic coast of the United States is more vulnerable because of the combined effects of global sea level rise, dynamic sea level rise (projected effects of Gulf Stream current velocity), and land subsidence due to post-glacial rebound effects. The Partnership for the Delaware Estuary is encouraging planning for 1.2 m (or more) of relative local sea level rise for every 1 m of global sea level rise due to the combination of these factors (Kreeger et al. 2010, Najjar et al. 2012). Over the past 100 years, the rate of sea level rise in the Delaware Estuary has averaged approximately 0.32 cm/yr (NOAA 2012). But to reach 1 m or more by 2100, which has been widely adopted for planning purposes (Kreeger et al., 2010; Najjar et al., 2012), rates of sea level rise in the Delaware Estuary will need to surpass 1 cm/yr sometime around 2040 (Kreeger and Homsey, 2012). Geologic history suggests that few tidal marshes existed in the Mid-Atlantic when the rate was this high during rapid ice melt periods (Psuty 1986; Psuty and Collins 1996); therefore, it is plausible that many coastal wetlands, especially microtidal salt marshes, could reach a tipping point for sustainability sometime in the next 30 years (Fig. 5.30 in Kreeger and Homsey, 2012). Already, rates of coastal wetland loss have averaged more than 2% between 1996 and 2006 (Kreeger and Homsey, 2012).

Sea level rise can influence wetlands in many ways. Salt marshes at the seaward edge of the estuary must maintain their elevation relative to sea level to prevent conversion to open water. Both plant production and sedimentation are processes that influence vertical marsh accretion rates. Salt marsh plants are adapted to tidal flooding to a certain physiological limit beyond which, they will become stressed. Inorganic material makes up less than 5% of the soil volume but is extremely important for maintaining marshes at an elevation where plant growth can continue. If soils do not accumulate enough organic and inorganic materials to overcome the rate of sea level rise and geologic subsidence, marshes will fall below the tides. Accretion can increase as sea level increases up to a particular (tipping) point, and beyond this the wetlands cannot keep up and will ultimately subside below the water. Therefore, it is important to assess the response of wetlands to sea level rise over time by obtaining continuous accretion data, which must be adjusted for land subsidence. For these reasons, the design of SSIM placed particular emphasis on using the latest and best methods for assessing surface elevation changes in the study marshes.

Biological monitoring in SSIM also closely examined shifts in plant and animal communities and production along tidal zonation gradients as a means to monitoring how sea level rise affects our wetlands. Shifts in biological communities (and associated ecosystem services) could occur because of saltwater intrusion into fresh and brackish areas (e.g., see Fig. 5.21 in Kreeger and Homsey, 2012), as well as landward migration of the marshes themselves (see Appendix G in Kreeger et al. 2010). In areas where marsh migration is not precluded by development, hard structure, and/or a steep upland slope, shoreline transgression under relative sea level rise forces coastal marshes to migrate landward and upward (Kraft et al. 1992, Warren and Niering 1993, Donnelly and Bertness 2001). Landward migration can cause a shift in species composition wherein low marsh species will replace mid- and high marsh species, and likewise, salt marshes can replace brackish and fresh water marshes. However, in areas where marsh migration is precluded by development and/or a steep upland slope, community shifts would also favor a replacement of higher intertidal species by lower species but ultimately tidal flooding would limit plant survival. In other words, relative sea level rise could cause an inland migration of marshes and species shifts in some areas and species shifts and marsh loss in other locations depending on the degree of development and the slope of the land inland of the wetlands. Indicators of wetland migration due to sea level rise include shifts in plant communities, plant morphology, and topographical changes over time. Therefore, in SSIM, examining elevation change along with spatially-explicit plant community, and vegetation characteristics such as height, stem density, and above-and belowground biomass allows us to assess both physical and biological changes to wetlands over time.

In tidal freshwater wetlands, an increase in salinity associated with sea level rise may occur over short time periods such as with a storm surge or over a longer time period as with a gradual increase in sea level. Salt water intrusion to brackish and fresh water marshes may have a severe impact on the plant and microbial communities, particularly when there is a lack of flushing by fresh water through precipitation and/or streamflow (Weston, 2006; Craft et al., 2008, Weston et al., 2009). When pore water salt concentrations remain high, plant species adapted to lower salinity will become stressed and less productive, and may die, potentially leading to conversion to open water. The pathways for anaerobic decomposition will also be altered by an influx of sea water to fresh water wetlands. Anaerobic decomposition in fresh water wetlands in dominated by the reduction of carbon dioxide (CO_2) to methane (CH_4) pathway. An introduction of sea water containing sulfate would potentially increase the rate at which organic matter is decomposed due to a more efficient pathway of sulfate (SO_4-$_3$) reduction. Thus, plant community and biomass, salinity, soil quality, and accretion measurements are important indicators for documenting change in salinity over time.

In addition to climate and sea level change factors, there are a number of ways in which humans have altered our environment to affect coastal wetland extent, condition, and function. Coastal development, groundwater withdrawal, altered sediment load, and increased nutrient load are a few of the ways in which we have impacted wetlands. Where feasible, core metrics in SSIM sought to also examine the importance of these stressors on marsh health and function. Six central questions guided final selection of SSIM metrics:

1. Are wetlands keeping up with sea level rise?
2. Are plant zones and plant morphology changing over time?
3. Is peak above- and belowground biomass changing and how does it contribute to accretion?
4. Is soil and water chemistry changing over time and is it related to accretion?
5. Is there a change in faunal abundance over time?

To address these five questions we implemented intensive field-based measurements that included wetland elevation, surface elevation and accretion changes, above- and belowground plant biomass, plant community and faunal integrity, algal biomass, and soil and water column nutrients. The design and initial implementation of SSIM wetland monitoring was initiated in 2010 and, along with initial data collection, thereafter continued through 2011. Presented in this Final Report are the locations of wetland monitoring sites, experimental design and methodology, GPS coordinates of permanent reference points and plots, and initial baseline data analyses and interpretation.

Methods

A more detailed description of all methods can be found in the QAPP (Appendix A).

Monitoring Locations

The Delaware Estuary is a coastal plain estuary that extends from the head of tides at Trenton, New Jersey and meets the Atlantic Ocean at Cape May, New Jersey to the north and Lewes, Delaware to the south (Figure 1). Wetlands along the estuary grade from salt marsh in the lower estuary, brackish in the mid-estuary, and tidal fresh in the upper estuary. Nutrient loading is relatively high particularly in the urban corridor around Philadelphia. Three wetland monitoring sites were established, which range the salinity gradient: 1) Tinicum, tidal fresh marsh in the John Heinz NWR south of Philadelphia, PA, 2) Christina River, tidal fresh marsh, south of Wilmington, DE, and 3) Maurice River, salt marsh, Maurice, NJ. These sites were chosen by a panel of partners that included The Academy of Natural Sciences – Patrick Center (ANSP), Partnership for Delaware Estuary (PDE), State of New Jersey – Department of Environmental Protection (NJ DEP), Rutgers University, and U.S. Fish and Wildlife Service.

The method of choosing locations is outlined below. By using the below criteria we hoped to establish monitoring locations that have a dual research purpose. This protocol was the start of a larger methodology to establish consistent criteria in site selection for all SSIM locations as part of the MACWA program with an ideal number of eventual SSIM stations for the Delaware Estuary planned to be six (2 in DE, 1 in PA, 3 in NJ). The three stations we selected therefore represent the first half of the overall Tier 4 network for MACWA (1 in DE, 1 in PA, 1 in NJ).

Monitoring Objectives

The objectives of the Delaware Estuary SSIM program are two-fold: 1) to assess surface elevation changes relative to sea level and other environmental stressors, and 2) to help understand the processes that maintain marsh elevation. Therefore, of all the potential metrics that could be monitored at fixed wetland stations, SSIM focuses on physical conditions (principally to understand surface elevation changes and associated effects on processes) and associated biological conditions (that can in turn affect physical conditions, such as via organic matter accumulation). In comparison to the original metrics list envisioned for MACWA in 2008 (Kreeger and Jacobs), final core metrics placed added emphasis on surface elevation and biological integrity, and detailed water quality and floristic metrics were considered to be supplemental metrics to be assessed if additional funding was obtained.

Surface Elevation Changes

The first objective was to determine elevation change over time in wetlands along the estuary study sites. For each of the three study marshes (Christina, Maurice, Tinicum), three SSIM stations were established: low tributary nearest main estuary, middle tributary, and upper tributary. Distances of study sites from the main estuary varied among study marshes but were generally within 5-6 km of the mouth of the tributaries. By including 3 sites per study marsh (instead of one as per the original grant proposal), we significantly strengthened the scientific integrity of the project.

Surface elevation studies at each of the 3 sites (3 per study marsh, 9 overall) consisted of one surface elevation table (SET) and multiple marker horizons (MHs). SETs were installed by sinking a stainless steel rod deep into the marsh until reaching impenetrable conditions (see below and Appendix A). Hence, changes in the elevation of the top of the rod (fitted with a receiver cap) reflect changes in absolute elevation due to subsidence, whereas changes in the elevation of the marsh surface reflect both subsidence/compaction and surface accretion (or erosion). By pairing MHs that assess surface accretion only with SETs that assess subsidence and accretion, the relative effects of subsidence and accretion can be discerned (Cahoon et al. 2002). Use of multiple MHs per SET strengthened the accuracy of surface accretion measures, which can vary spatially across the marsh platform. All SETs and MHs were deployed on the marsh platform, which mainly consisted of high marsh vegetation, varying from 50-400 m landward of the main tributary creek/river edge.

The true baseline elevation of installed SETs was initially benchmarked against local sea level (i.e, NAVD88 tidal gages) approximately one month following installation (to allow disturbance effects to stabilize). Typically, it takes two years or more for SETs and MHs to fully stabilize and begin yielding scientifically accurate data for subsidence and accretion processes, since these processes occur on fine millimeter scales.

Surface elevation data can be compared among sites within a study marsh (i.e. distances to open water) or among study marshes. In addition, recent acquisition of addition funding for MACWA SSIM efforts in New Jersey (from EPA R2) have enabled expansion of stations to include marshes in Barnegat Bay, enabling comparisons between Delaware Bay and an estuary along the Atlantic Coast. The MACWA SSIM design and methods are now being further exported to additional estuaries, such as within salt marshes of New York City. By broadening the SSIM network in this way, we expect to eventually further strengthen our understanding of the general processes that help to maintain marsh elevation and high plant productivity that might occur concomitantly with differences in tidal range, sediment sources and availability, marsh productivity and plant types, nutrients, and the degree of development and shoreline impacts. These differences can provide an opportunity to test specific hypotheses regarding the processes that control marsh accretion and elevation. For the first objective, we need a broad spatial coverage along the Bay, balanced against the local data scale (~ <1 m^2) that is provided by a SET-MH. There will be tradeoffs in the development of this monitoring program relative to financial constraints and staff availability. Currently, no funding is available to sustain two of the inaugural monitoring stations that were installed in this study (Christina and Tinicum), for example (Fig. 5).

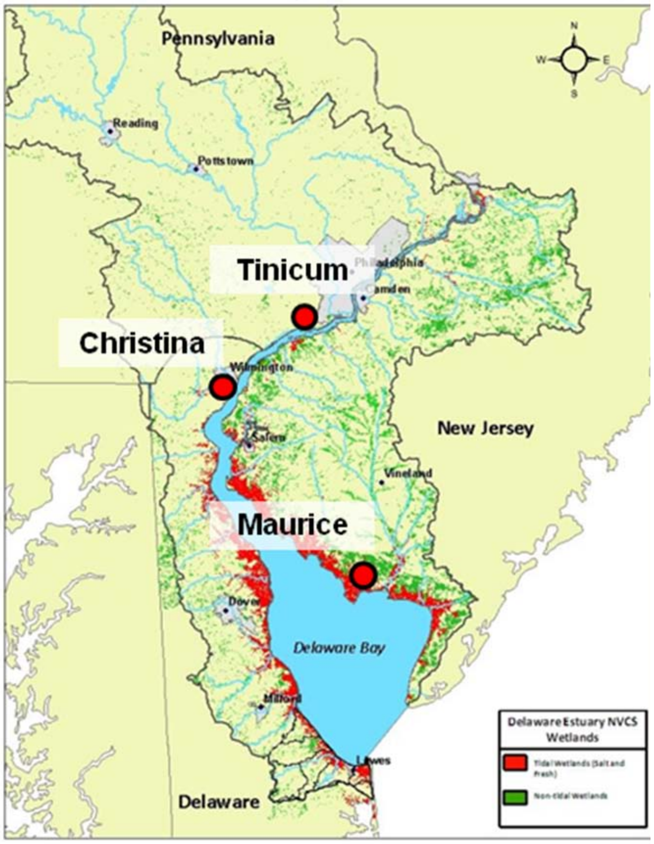

Figure 5. Delaware Estuary SSIM stations.

Delaware Bay is characterized by salinity and nutrient gradients from the mouth of the bay to the upper estuary near Trenton, New Jersey. Wetlands along the Delaware Bay range from tidal fresh water to salt marshes. Tidal fresh water wetlands differ from salt marshes in many respects including salinity, vegetation community, and hydrology and tidal range. To evaluate surface elevation changes in wetlands along the bay, the three stations installed (Fig. 5) spanned the salinity gradient from the upper to lower bay. Tinicum (Pennsylvania) is generally oligohaline, the Christina River (Wilmington, Delaware) is oligohaline to sometimes slightly brackish, and wetlands along the lower Maurice River (New Jersey)

Within each study marsh, the three individual SET-MH locations were installed in interior marsh areas (i.e., not on the creek bank). The arrangement of SETs and associated transects used to monitor zonation gradients varied among study marshes to take advantage of and best represent local conditions (compare Figs 6 and 7). For example, in one marsh, a linear array of SETs was used along a distance gradient from the main water body (Fig. 6), whereas, in other places three approximately parallel transects were installed that were perpendicular to and on alternating sides of the main tidal channel at increasing distances from the main water body (Fig. 7). In all cases however, SET-MHs were established so that SET 1 was approximately 50-100 m from the water, SET 2 was approximately 200 m back, and SET 3 was approximately 400 m back. The actual distances from water depended on the overall area of the marsh, abundance of small drainage ditches, etc.. This design sought to account for spatial variation in sediment supply since as distance from the main water body increases, sediment availability decreases. Because accretion rates along creek banks have been shown to be greater than those in interior areas, SET-MH locations were always set back greater than 20 m from the creek bank or shoreline to avoid these natural levee effects. Other marsh surface features (i.e., mosquito ditches; interior ponds, etc.) were also taken into consideration when locating each SET-MH location. In wetlands with mosquito ditches, we placed SET-MH locations between ditches, and not near ditch banks.

At the tidal freshwater site at Tinicum, SETs were installed along a single transect perpendicular to Darby Creek (Fig. 8). SETs were installed on July 20, 2010. SETs were established at approximately 55, 200, and 250 m from the channel (SET 1, 3, and 2, respectively) and were located in different dominant plant communities.

SETs in the oligohaline wetland along the Christina River were placed along a single transect perpendicular to the main river channel on September 17, 2010 (Fig. 9). SETs were established at approximate distances of 25, 230, 410 m from the main river, although distances to nearest tidal creeks vary.

SETs were established along the Maurice River on October 13, 2010 along a linear transect perpendicular to the main channel (Fig. 10). SETs were placed at 100, 200, and 570 m distances from the main channel. Because of the meandering nature of the Maurice River at this location, SET 3 is located only 235 m from the nearest

Figure 6. General surface elevation table and marker horizon (SET-MH) transect linear design option for wetland monitoring sites. Distances from water bodies will vary depending on marsh area and topography.

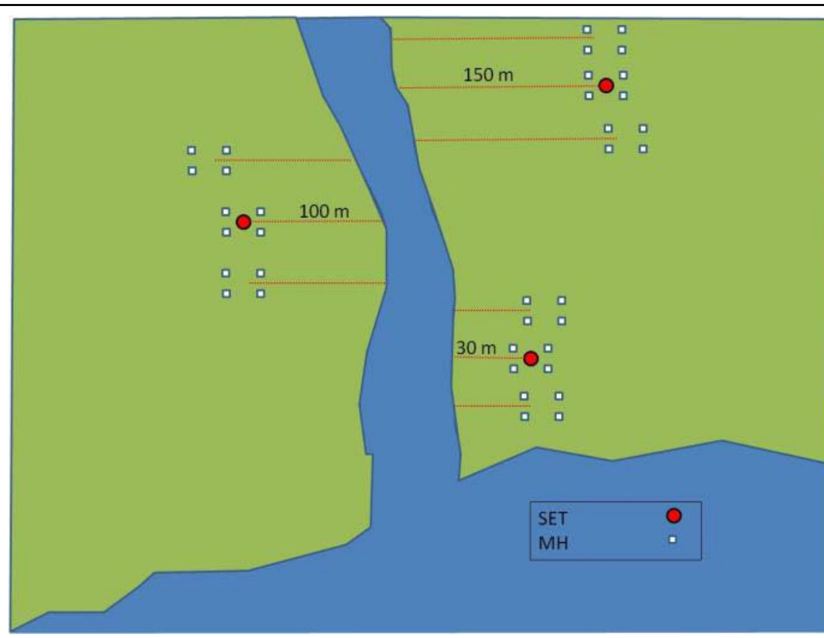

Figure 7. General surface elevation table and marker horizon (SET-MH) transect design along alternating sides of tidal channel. Distances from water bodies will vary depending on marsh area and topography.

section of the main channel.

The installation and sampling dates are summarized in Table 1. Data were collected at SET-MH locations beginning in the spring 2011, and gain in fall 2011; and in the future data are expected to be continued two times per year contingent on future funding. Surficial accretion of material is being determined by measuring the vertical increments of accumulation over defined time periods above the MHs placed on the marsh surface at the beginning of the study (as per Cahoon and Turner 1989).

Figure 8. SET locations at Tinicum, PA. SET 1 is located at 39°52'54.29"N, 75°16'38.45"W; SET 2 is at 39°52'58.76"N, 75°16'43.37"W; and SET 3 at 39°53'1.28"N, 75°16'45.30"W.

MHs consisted of feldspar, and per SET there were three MHs in plots adjacent to the SET. Therefore each study marsh has nine marker horizon plots (3 per SET). Short-term sedimentation rates will be determined by collecting two cores in each plot area four times per year for measurement of sediment accumulation above the marker horizon. Due to differences among wetlands in sedimentation rates and soil texture, cryocoring techniques using liquid nitrogen have also been used for surface accretion determination.

Figure 9. SET locations Christina River, DE. SET 1 is located at 39°43'12.67"N, 75°33'44.18"W; SET 2 is at 39°43'16.24"N, 75°33'51.58"W; and SET 3 at 39°43'19.33"N, 75°33'57.88"W.

Figure 10. SET locations along the Maurice River, New Jersey. SET 1 is located at 39°14'39.03"N, 75° 0'53.37"W, SET 2 is at 39°14'37.61"N, 75° 0'49.90"W; and SET 3 is located at 39°14'31.19"N, 75° 0'37.22"W.

Table 1. Installation date, location, and depth of surface elevation tables (SET) in Tinicum, Christina, and Maurice in the Delaware Estuary.

ESTUARY	Date of Install	SITE	SET #	LAT	LONG	# rods	Depth (m)
Delaware Bay	7/20/2010	Tinicum, PA (John Heinz NWR)	1	39°52'54.29" N	75°16'38.55" W	12.5	15.2
			2	39°52'58.71" N	75°16'43.45" W	7.5	9.1
			3	39°53'01.19" N	75°16'45.29" W	4.5	5.5
	9/17/2010	Christina River, DE	1	39°43'12.67" N	75°33'44.18" W	10	12.2
			2	39°43'16.24" N	75°33'51.58" W	10	12.2
			3	39°43'19.33" N	75°33'57.88" W	8	9.8
	10/13/2010	Maurice River, NJ	1	39°14'39.03"N	75° 0'53.37"W	19	23.2
			2	39°14'37.61"N	75° 0'49.90"W	31	37.8
			3	39°14'31.19"N	75° 0'37.22"W	17	20.7

Plant Community

Plant community assemblage was characterized using three methods: 1) line transects; 2) permanent plots; and 3) random edge vegetation plots. In order to examine plant community (ie., dominant species) change over time once per year at peak biomass (July/August) line transect(s) that have been established for SETs and two parallel replicate lines were surveyed using RTK GPS within each fixed station study site (Fig. 11). To monitor plant community changes over time baseline latitude, longitude and elevation measurements were made using survey grade GPS RTK (Leica GX1230 GG) paired with a GNSS Base station (AX1202 GG) to achieve cm scale accuracy. Data points are taken from the marsh edge every 25m or when there is a shift in the primary or secondary species present to 25 m beyond the final SET. At least three replicate transects were established in each study marsh. Emergent macrophyte species that were within a square meter of the line were identified. RTK GPS was used to mark the location and elevation of plant community changes along transects. Using the data from previous years, this same transect was revisited in subsequent years and major changes in plant communities were determined.

A total of nine permanent 1 m^2 quadrats were established and marked with stakes along transect lines at each site. Three replicate plots (n = 3) were established at the marsh edge, and two at distances from the marsh edge to the marsh. The plant community assemblage was characterized within each quadrat by determining the species present, invasive species, percent cover by species, and stem height for the first 25 stems and light intensity at the sediment surface was recorded. Six random edge plots were established to harvest and measure fauna and to measure vegetation characteristics similar to that in the permanent plots (see Appendix A for additional details on all methods**)**.

The locations of permanent vegetation sampling plots are shown in Table 2. The times and locations of sampling for changes in dominant vegetation along line transects in the Tinicum, Christina and Maurice study marshes is summarized in Tables 3-5.

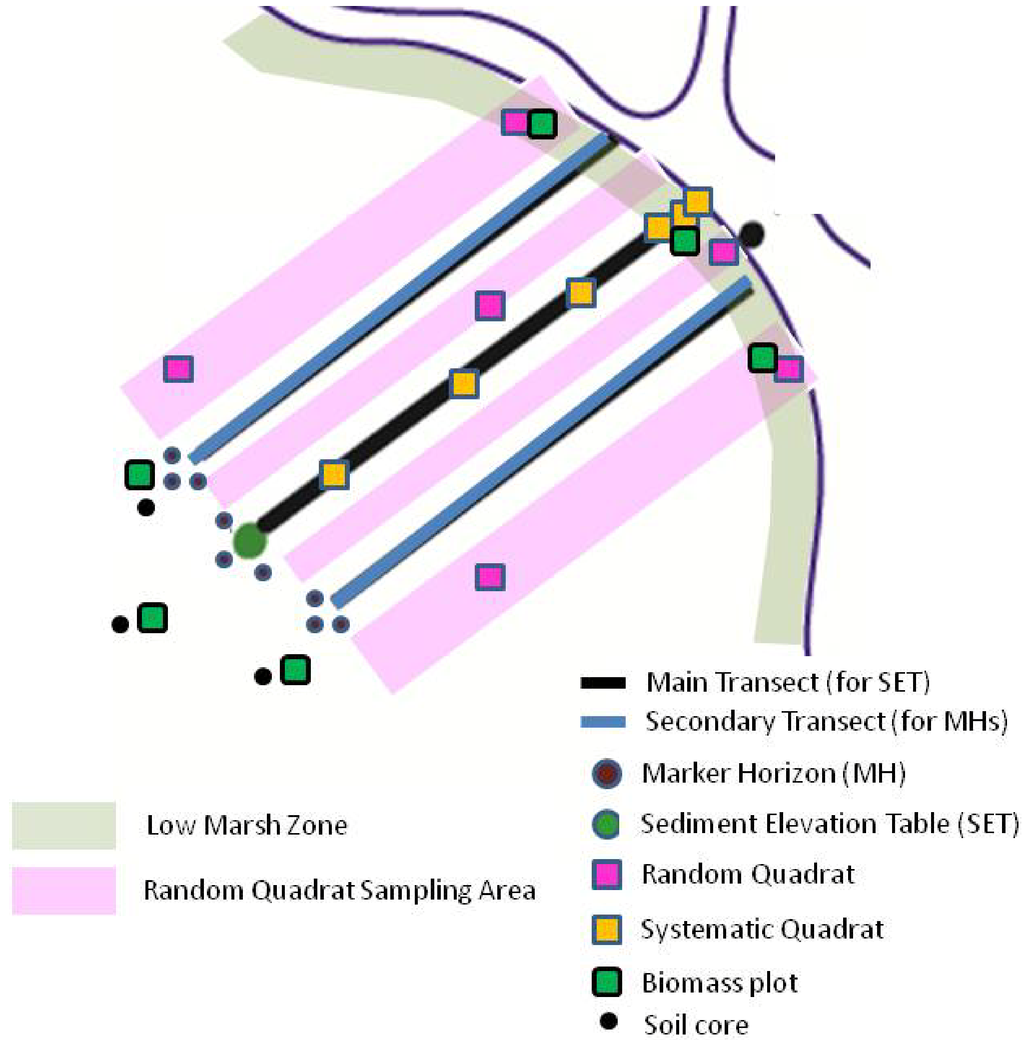

Figure 11. Typical layout of a SET study site showing replication of various bioassessment plots. This design was modified for sites having SETs arranged linearly, however the degree of replication for bioassessment plots was balanced among all sites.

Table 2. Location of permanent vegetation plots in wetland monitoring stations.

ESTUARY	SITE	Plot #	LAT	LONG
Delaware Bay	Tinicum, PA	1	39°52'52.68"N	75°16'38.88"W
		2	39°52'52.68"N	75°16'39.68"W
		3	39°52'52.59"N	75°16'40.70"W
		4	39°52'56.86"N	75°16'39.16"W
		5	39°52'56.39"N	75°16'39.98"W
		6	39°52'55.87"N	75°16'40.98"W
		7	39°53'1.13"N	75°16'44.81"W
		8	39°53'0.83"N	75°16'45.60"W
		9	39°53'0.44"N	75°16'46.28"W
	Christina River, DE	1	39°43'12.56"N	75°33'42.96"W
		2	39°43'12.21"N	75°33'43.49"W
		3	39°43'11.72"N	75°33'44.16"W
		4	39°43'17.62"N	75°33'53.48"W
		5	39°43'17.02"N	75°33'53.88"W
		6	39°43'16.63"N	75°33'54.37"W
		7	39°43'20.38"N	75°33'59.13"W
		8	39°43'19.95"N	75°33'59.72"W
		9	39°43'19.37"N	75°34'0.33"W
	Maurice River, NJ	1	39°14'40.69"N	75° 0'57.36"W
		2	39°14'41.23"N	75° 0'56.93"W
		3	39°14'41.79"N	75° 0'56.66"W
		4	39°14'38.24"N	75° 0'52.66"W
		5	39°14'38.68"N	75° 0'52.23"W
		6	39°14'38.99"N	75° 0'51.77"W
		7	39°14'34.85"N	75° 0'44.98"W
		8	39°14'35.41"N	75° 0'44.33"W
		9	39°14'35.93"N	75° 0'43.74"W

Table 3. Time, location, elevation and dominant plant species along line transects in Tinicum, PA.

Date/Time	Transect	Latitude	Longitude	Ortho Ht (m)	Dom Spp	Subdom Spp
8/5/2011 7:07	1	39° 53' 01.71925" N	75° 16' 47.37444" W	0.8837	*Peltandra virginica*	morning glory spp.
8/5/2011 7:10	1	39° 53' 00.96192" N	75° 16' 46.91892" W	0.7458	*Zizania aquatica*	*Peltandra virginica*
8/5/2011 7:13	1	39° 53' 00.50422" N	75° 16' 46.63600" W	0.7569	*Peltandra virginica*	*Zizania aquatica*
8/5/2011 7:14	1	39° 53' 00.25421" N	75° 16' 46.33590" W	0.741	*Schoenoplectus ezytheroides*	*Peltandra virginica*
8/5/2011 7:15	1	39° 53' 00.09807" N	75° 16' 46.20245" W	0.7263	*Polygonum punctatum*	*Peltandra virginica*
8/5/2011 7:17	1	39° 52' 59.82921" N	75° 16' 45.95927" W	0.3087	*Peltandra virginica*	*Zizania aquatica*
8/5/2011 8:10	1	39° 52' 52.67396" N	75° 16' 37.87066" W	-0.2434	*Nuphar lutea*	
8/5/2011 8:12	1	39° 52' 53.14924" N	75° 16' 38.24781" W	0.5839	*Zizania aquatica*	*Nuphar lutea*
8/5/2011 8:14	1	39° 52' 53.43862" N	75° 16' 38.65613" W	0.5338	*Sagittaria latifolia*	*Nuphar lutea*
8/5/2011 8:16	1	39° 52' 53.99466" N	75° 16' 39.72828" W	0.4013	*Nuphar lutea*	*Zizania aquatica*
8/5/2011 8:17	1	39° 52' 54.31325" N	75° 16' 40.54561" W	0.4239	*Nuphar lutea*	
8/5/2011 8:19	1	39° 52' 54.95286" N	75° 16' 41.43401" W	0.2743	*Nuphar lutea*	
8/5/2011 8:20	1	39° 52' 55.55281" N	75° 16' 42.29243" W	0.3381	*Nuphar lutea*	
8/5/2011 8:21	1	39° 52' 56.17743" N	75° 16' 42.79835" W	0.4367	*Sagittaria latifolia*	*Zizania aquatica*
8/5/2011 8:24	1	39° 52' 56.79106" N	75° 16' 43.48978" W	-0.2916	*Nuphar lutea*	
8/5/2011 8:25	1	39° 52' 56.84274" N	75° 16' 43.57542" W	-0.6785	*Nuphar lutea*	
8/5/2011 8:26	1	39° 52' 57.26802" N	75° 16' 43.85650" W	-0.7017	*Nuphar lutea*	
8/5/2011 8:28	1	39° 52' 57.93570" N	75° 16' 44.28715" W	0.2614	*Nuphar lutea*	
8/5/2011 8:30	1	39° 52' 58.26655" N	75° 16' 44.59942" W	0.3341	*Zizania aquatica*	*Nuphar lutea*
8/5/2011 8:31	1	39° 52' 58.73657" N	75° 16' 45.17448" W	0.3493	*Nuphar lutea*	*Zizania aquatica*
8/5/2011 8:32	1	39° 52' 59.35187" N	75° 16' 45.63745" W	-0.0909	*Nuphar lutea*	
8/5/2011 7:23	2	39° 53' 00.63786" N	75° 16' 45.15537" W	0.5599	*Zizania aquatica*	*Peltandra virginica*
8/5/2011 7:25	2	39° 53' 00.80960" N	75° 16' 45.30565" W	0.4595	*Peltandra virginica*	*Zizania aquatica*
8/5/2011 7:26	2	39° 53' 01.26091" N	75° 16' 45.62745" W	0.7118	*Zizania aquatica*	*Peltandra virginica*
8/5/2011 7:27	2	39° 53' 01.52248" N	75° 16' 45.85000" W	0.7663	*Typha angustifolia*	*Peltandra virginica*
8/5/2011 7:29	2	39° 53' 01.81825" N	75° 16' 46.09599" W	0.8074	*Peltandra virginica*	morning glory spp.
8/5/2011 7:31	2	39° 53' 02.28733" N	75° 16' 46.46022" W	0.8491	*Peltandra virginica*	morning glory spp.
8/5/2011 8:36	2	39° 52' 59.72577" N	75° 16' 44.17983" W	-0.2495	*Nuphar lutea*	
8/5/2011 8:39	2	39° 52' 59.05253" N	75° 16' 43.54829" W	0.3033	*Nuphar lutea*	
8/5/2011 8:40	2	39° 52' 58.36277" N	75° 16' 42.81397" W	-0.0458	*Nuphar lutea*	
8/5/2011 8:43	2	39° 52' 58.16217" N	75° 16' 42.49380" W	-0.6238	*Nuphar lutea*	
8/5/2011 9:20	2	39° 52' 52.63288" N	75° 16' 36.87577" W	-0.3489	*Nuphar lutea*	
8/5/2011 9:21	2	39° 52' 53.04785" N	75° 16' 37.16162" W	0.3457	*Zizania aquatica*	*Nuphar lutea*
8/5/2011 9:25	2	39° 52' 53.19043" N	75° 16' 37.25660" W	-0.187	*Zizania aquatica*	*Nuphar lutea*
8/5/2011 9:25	2	39° 52' 53.29726" N	75° 16' 37.34515" W	0.4893	*Zizania aquatica*	*Nuphar lutea*
8/5/2011 9:27	2	39° 52' 53.85518" N	75° 16' 37.81485" W	0.4347	*Nuphar lutea*	*Zizania aquatica*
8/5/2011 9:29	2	39° 52' 54.22978" N	75° 16' 38.17827" W	0.3229	*Nuphar lutea*	
8/5/2011 9:30	2	39° 52' 54.79286" N	75° 16' 38.71305" W	0.3268	*Zizania aquatica*	*Nuphar lutea*
8/5/2011 9:31	2	39° 52' 54.90248" N	75° 16' 38.81617" W	0.2703	*Nuphar lutea*	*Zizania aquatica*
8/5/2011 9:32	2	39° 52' 55.51162" N	75° 16' 39.46120" W	0.3088	*Nuphar lutea*	
8/5/2011 9:34	2	39° 52' 56.13026" N	75° 16' 40.14054" W	0.3055	*Sagittaria latifolia*	*Nuphar lutea*
8/5/2011 9:36	2	39° 52' 56.65539" N	75° 16' 40.69631" W	0.3422	*Zizania aquatica*	*Nuphar lutea*
8/5/2011 9:37	2	39° 52' 56.89898" N	75° 16' 41.00330" W	0.3064	mix *N. lutea/Z. aquatica*	mix *S. latifolia/P. ch*
8/5/2011 9:38	2	39° 52' 57.10282" N	75° 16' 41.19161" W	0.3817	*Nuphar lutea*	
8/5/2011 9:40	2	39° 52' 57.59454" N	75° 16' 41.81308" W	0.2755	*Nuphar lutea*	
8/5/2011 9:41	2	39° 52' 57.80769" N	75° 16' 42.01256" W	-0.5563	*Nuphar lutea*	
8/5/2011 7:33	3	39° 53' 02.44929" N	75° 16' 45.47207" W	0.7008	*Peltandra virginica*	
8/5/2011 7:36	3	39° 53' 01.91337" N	75° 16' 45.17530" W	0.6773	*Peltandra virginica*	*Typha angustifolia*
8/5/2011 7:37	3	39° 53' 01.60607" N	75° 16' 44.81736" W	0.7487	mix *P. virginica/Z. aquatica*	
8/5/2011 7:40	3	39° 53' 01.16221" N	75° 16' 44.01379" W	0.1065	*Nuphar lutea*	
8/5/2011 7:42	3	39° 53' 00.79590" N	75° 16' 44.03258" W	-0.4584	*Nuphar lutea*	
8/5/2011 8:45	3	39° 52' 58.91517" N	75° 16' 41.61197" W	-0.819	*Nuphar lutea*	
8/5/2011 8:47	3	39° 52' 59.65909" N	75° 16' 42.20318" W	0.2634	*Nuphar lutea*	
8/5/2011 8:49	3	39° 53' 00.34666" N	75° 16' 43.01894" W	-0.0788	*Nuphar lutea*	
8/5/2011 8:49	3	39° 53' 00.57003" N	75° 16' 43.32152" W	-0.2782	*Nuphar lutea*	
8/5/2011 8:55	3	39° 52' 58.61259" N	75° 16' 41.09672" W	-0.7536	*Nuphar lutea*	
8/5/2011 8:58	3	39° 52' 58.25156" N	75° 16' 40.54217" W	0.2466	*Pontederia chordata*	*Nuphar lutea*
8/5/2011 8:59	3	39° 52' 57.96758" N	75° 16' 40.23073" W	0.4534	*Zizania aquatica*	*Nuphar lutea*
8/5/2011 9:00	3	39° 52' 57.77381" N	75° 16' 40.07813" W	0.3195	*Nuphar lutea*	*Sagittaria latifolia*
8/5/2011 9:01	3	39° 52' 57.26234" N	75° 16' 39.65652" W	0.3802	*Sagittaria latifolia*	*Pontederia chordatc*
8/5/2011 9:05	3	39° 52' 56.83585" N	75° 16' 39.23302" W	0.3503	*Zizania aquatica*	mix S. latifolia/N. lu
8/5/2011 9:05	3	39° 52' 56.65694" N	75° 16' 39.13664" W	0.4362	*Sagittaria latifolia*	*Zizania aquatica*
8/5/2011 9:07	3	39° 52' 56.52334" N	75° 16' 39.01497" W	0.31	*Acorus calamus*	*Nuphar lutea*
8/5/2011 9:08	3	39° 52' 56.32715" N	75° 16' 38.87835" W	0.339	*Nuphar lutea*	*Acorus calamus*
8/5/2011 9:09	3	39° 52' 55.52176" N	75° 16' 38.14681" W	0.1508	*Nuphar lutea*	
8/5/2011 9:11	3	39° 52' 54.50264" N	75° 16' 37.16210" W	0.314	*Zizania aquatica*	*Nuphar lutea*
8/5/2011 9:12	3	39° 52' 54.19088" N	75° 16' 36.89049" W	0.4202	*Pontederia chordata*	*Nuphar lutea*
8/5/2011 9:13	3	39° 52' 54.03584" N	75° 16' 36.83493" W	0.3877	*Zizania aquatica*	*Nuphar lutea*
8/5/2011 9:15	3	39° 52' 53.50496" N	75° 16' 36.28482" W	0.5822	*Zizania aquatica*	*Nuphar lutea*
8/5/2011 9:16	3	39° 52' 53.16250" N	75° 16' 35.87916" W	0.4401	*Nuphar lutea*	*Zizania aquatica*
8/5/2011 9:17	3	39° 52' 52.52775" N	75° 16' 35.22175" W	-0.2234	*Nuphar lutea*	

Table 4**.** Time, location, elevation and dominant plant species along line transects in Christina River, Delaware Estuary, DE.

Date/Time	Transect	Date/Time	Latitude	Longitude	Ortho Ht (m)	Dom Spp	Subdom Spp
7/13/2011 12:08	1	7/13/2011 12:08	39° 43' 18.81131" N	75° 33' 55.31529" W	0.6896	*Peltandra virginica*	*Typha angustifolia*
7/13/2011 12:11	1	7/13/2011 12:11	39° 43' 19.20260" N	75° 33' 56.08420" W	0.6912	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 12:13	1	7/13/2011 12:13	39° 43' 19.27854" N	75° 33' 56.61466" W	0.571	*Typha angustifolia*	mix *P. virginica/A. cannabinus*
7/13/2011 12:22	1	7/13/2011 12:22	39° 43' 18.48583" N	75° 33' 54.12005" W	0.6224	*Peltandra virginica*	*Typha angustifolia*
7/13/2011 12:26	1	7/13/2011 12:26	39° 43' 18.45173" N	75° 33' 54.02064" W	0.5419	*Nuphar lutea*	*Peltandra virginica*
7/13/2011 12:28	1	7/13/2011 12:28	39° 43' 18.37777" N	75° 33' 53.93586" W	0.5369	*Typha angustifolia*	*Pontederia chordata*
7/13/2011 12:31	1	7/13/2011 12:31	39° 43' 17.65910" N	75° 33' 53.53434" W	0.7037	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 12:45	1	7/13/2011 12:45	39° 43' 17.18465" N	75° 33' 52.61608" W	0.5425	*Peltandra virginica*	*Typha angustifolia*
7/13/2011 12:46	1	7/13/2011 12:46	39° 43' 17.39398" N	75° 33' 52.42883" W	0.81	*Nuphar lutea*	*Sagittaria latifolia*
7/13/2011 12:49	1	7/13/2011 12:49	39° 43' 17.10767" N	75° 33' 51.07241" W	0.5082	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 12:53	1	7/13/2011 12:53	39° 43' 16.40851" N	75° 33' 50.24703" W	0.7287	*Typha angustifolia*	*Impatiens capensis*
7/13/2011 14:10	1	7/13/2011 14:10	39° 43' 12.85774" N	75° 33' 43.86906" W	0.6638	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 14:13	1	7/13/2011 14:13	39° 43' 13.24275" N	75° 33' 44.45980" W	0.5292	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 14:13	1	7/13/2011 14:13	39° 43' 13.31704" N	75° 33' 44.48687" W	0.4686	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 9:58	2	7/13/2011 9:58	39° 43' 19.33035" N	75° 33' 58.46321" W	0.6664	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 10:03	2	7/13/2011 10:03	39° 43' 19.92081" N	75° 33' 59.82204" W	0.6901	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 10:05	2	7/13/2011 10:05	39° 43' 20.12915" N	75° 33' 59.83969" W	0.7102	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 10:30	2	7/13/2011 10:30	39° 43' 19.08587" N	75° 33' 57.22418" W	0.5402	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 10:41	2	7/13/2011 10:41	39° 43' 18.60622" N	75° 33' 56.44383" W	0.5996	*Sagittaria latifolia*	*Peltandra virginica*
7/13/2011 11:55	2	7/13/2011 11:55	39° 43' 17.08923" N	75° 33' 53.53934" W	0.662	*Typha angustifolia*	*Sagittaria latifolia*
7/13/2011 11:58	2	7/13/2011 11:58	39° 43' 17.39481" N	75° 33' 54.23378" W	0.6072	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 12:03	2	7/13/2011 12:03	39° 43' 17.97604" N	75° 33' 55.14191" W	0.5974	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 12:58	2	7/13/2011 12:58	39° 43' 15.56960" N	75° 33' 50.43717" W	0.6603	*Impatiens capensis*	*Peltandra virginica*
7/13/2011 13:01	2	7/13/2011 13:01	39° 43' 15.92622" N	75° 33' 51.36174" W	0.676	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 13:08	2	7/13/2011 13:08	39° 43' 16.26700" N	75° 33' 52.47627" W	0.4876	*Typha angustifolia*	
7/13/2011 13:10	2	7/13/2011 13:10	39° 43' 16.30805" N	75° 33' 52.67521" W	0.4612	*Pontederia chordata*	*Sagittaria latifolia*
7/13/2011 13:11	2	7/13/2011 13:11	39° 43' 16.35108" N	75° 33' 52.79768" W	0.5088	*Typha angustifolia*	*Sagittaria latifolia*
7/13/2011 13:12	2	7/13/2011 13:12	39° 43' 16.41492" N	75° 33' 53.01956" W	0.6481	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 13:57	2	7/13/2011 13:57	39° 43' 12.69833" N	75° 33' 45.06732" W	0.4273	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 14:01	2	7/13/2011 14:01	39° 43' 12.40940" N	75° 33' 43.91124" W	0.7669	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 14:05	2	7/13/2011 14:05	39° 43' 12.67657" N	75° 33' 42.92313" W	1.0101	*Scirpus fluviatilis*	*Typha angustifolia*
7/13/2011 9:33	3	7/13/2011 9:33	39° 43' 19.65615" N	75° 34' 00.52903" W	0.6778	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 9:35	3	7/13/2011 9:35	39° 43' 19.20277" N	75° 33' 59.42181" W	0.7322	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 9:39	3	7/13/2011 9:39	39° 43' 18.53628" N	75° 33' 58.67170" W	0.5856	*Peltandra virginica*	*Typha angustifolia*
7/13/2011 9:43	3	7/13/2011 9:43	39° 43' 17.68156" N	75° 33' 58.07441" W	0.6291	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 9:46	3	7/13/2011 9:46	39° 43' 17.48849" N	75° 33' 57.63071" W	0.6857	*Typha angustifolia*	*Impatiens capensis*
7/13/2011 13:17	3	7/13/2011 13:17	39° 43' 15.94123" N	75° 33' 53.39323" W	0.5557	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 13:20	3	7/13/2011 13:20	39° 43' 15.53701" N	75° 33' 52.53608" W	0.6338	*Peltandra virginica*	*Typha angustifolia*
7/13/2011 13:22	3	7/13/2011 13:22	39° 43' 15.15511" N	75° 33' 51.52049" W	0.7893	*Typha angustifolia*	*Impatiens capensis*
7/13/2011 13:25	3	7/13/2011 13:25	39° 43' 15.06907" N	75° 33' 51.41979" W	0.5441	*Typha angustifolia*	*Impatiens capensis*
7/13/2011 13:44	3	7/13/2011 13:44	39° 43' 11.68005" N	75° 33' 44.59482" W	0.8113	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 13:50	3	7/13/2011 13:50	39° 43' 11.92139" N	75° 33' 45.39655" W	0.617	*Impatiens capensis*	*Sagittaria latifolia*
7/13/2011 13:53	3	7/13/2011 13:53	39° 43' 12.33386" N	75° 33' 46.32192" W	0.7314	*Impatiens capensis*	*Sagittaria latifolia*
7/13/2011 13:53	3	7/13/2011 13:53	39° 43' 12.38077" N	75° 33' 46.35946" W	0.5861	*Impatiens capensis*	*Amaranthus cannabinus*
7/13/2011 11:41	3	7/13/2011 11:41	39° 43' 16.33322" N	75° 33' 56.44497" W	0.4778	*Typha angustifolia*	*Peltandra virginica*
7/13/2011 11:45	3	7/13/2011 11:45	39° 43' 16.77866" N	75° 33' 55.08808" W	0.7262	*Peltandra virginica*	*Typha angustifolia*
7/13/2011 11:49	3	7/13/2011 11:49	39° 43' 16.38423" N	75° 33' 53.77709" W	0.6164	*Typha angustifolia*	*Impatiens capensis*

Table 5**.** Time, location, elevation and dominant plant species along line transects in Maurice River, Delaware Estuary NJ.

Date/Time	Transect	Latitude	Longitude	Ortho Ht.	Dom Spp	Subdom Spp
6/28/2011 11:37	1	39° 14' 40.11199" N	75° 00' 58.04971" W	-0.3785	mud flat	
6/28/2011 11:39	1	39° 14' 40.04612" N	75° 00' 57.95156" W	-0.0294	*Spartina alterniflora* (med)	
6/28/2011 11:39	1	39° 14' 39.97012" N	75° 00' 57.81731" W	0.4805	*Phragmites australis*	
6/28/2011 11:40	1	39° 14' 39.91087" N	75° 00' 57.67288" W	0.733	*Spartina alterniflora* (med)	
6/28/2011 11:42	1	39° 14' 39.46433" N	75° 00' 57.04936" W	0.6362	*Spartina alterniflora* (med)	
6/28/2011 11:42	1	39° 14' 39.04691" N	75° 00' 56.44208" W	0.3029	*Spartina alterniflora* (med)	
6/28/2011 11:43	1	39° 14' 39.01251" N	75° 00' 56.39561" W	0.4587	*Spartina alterniflora* (med)	
6/28/2011 11:44	1	39° 14' 38.95073" N	75° 00' 56.26448" W	0.3496	*Spartina alterniflora* (med)	
6/28/2011 11:44	1	39° 14' 38.92469" N	75° 00' 56.23292" W	0.4887	*Spartina alterniflora* (med)	
6/28/2011 11:45	1	39° 14' 38.51510" N	75° 00' 55.76584" W	0.4771	*Spartina alterniflora* (med)	
6/28/2011 11:46	1	39° 14' 38.49361" N	75° 00' 55.74016" W	0.5572	*Spartina alterniflora* (med)	
6/28/2011 11:46	1	39° 14' 37.97353" N	75° 00' 55.25229" W	0.5699	*Spartina alterniflora* (med)	
6/28/2011 11:47	1	39° 14' 37.41444" N	75° 00' 54.79010" W	0.7144	*Spartina alterniflora* (med)	
6/28/2011 11:48	1	39° 14' 36.83124" N	75° 00' 54.40124" W	0.6436	*Spartina alterniflora* (med)	
6/28/2011 11:49	1	39° 14' 36.30997" N	75° 00' 53.92130" W	0.643	*Spartina alterniflora* (med)	
6/28/2011 11:50	1	39° 14' 35.64657" N	75° 00' 53.19258" W	0.7537	*Spartina alterniflora* (med)	
6/28/2011 11:59	1	39° 14' 38.08943" N	75° 00' 53.75636" W	0.7856	*Spartina alterniflora* (med)	
6/28/2011 12:01	1	39° 14' 37.78400" N	75° 00' 52.62335" W	0.817	*Spartina alterniflora* (med)	
6/28/2011 12:02	1	39° 14' 37.34141" N	75° 00' 51.58486" W	0.8552	*Spartina alterniflora* (med)	
6/28/2011 12:03	1	39° 14' 36.92595" N	75° 00' 50.42185" W	0.889	*Spartina alterniflora* (med)	
6/28/2011 12:05	1	39° 14' 36.46766" N	75° 00' 50.16473" W	0.7635	*Spartina alterniflora* (med)	
6/28/2011 12:07	1	39° 14' 36.34356" N	75° 00' 49.16969" W	0.902	*Spartina alterniflora* (med)	
6/28/2011 12:08	1	39° 14' 36.09959" N	75° 00' 48.06841" W	0.8951	*Spartina alterniflora* (med)	
6/28/2011 12:09	1	39° 14' 35.71259" N	75° 00' 47.04784" W	0.8515	*Spartina alterniflora* (med)	
6/28/2011 12:10	1	39° 14' 35.42371" N	75° 00' 46.25333" W	0.8875	*Spartina alterniflora* (med)	
6/28/2011 12:12	1	39° 14' 34.83178" N	75° 00' 45.58015" W	0.8443	*Spartina alterniflora* (med)	
6/28/2011 12:13	1	39° 14' 34.25789" N	75° 00' 44.90937" W	0.8487	*Spartina alterniflora* (med)	
6/28/2011 12:14	1	39° 14' 33.67026" N	75° 00' 44.19687" W	0.8688	*Spartina alterniflora* (med)	
6/28/2011 12:15	1	39° 14' 33.22083" N	75° 00' 43.45285" W	0.6342	*Spartina alterniflora* (med)	
6/28/2011 12:16	1	39° 14' 33.02286" N	75° 00' 42.95308" W	0.5869	*Spartina alterniflora* (med)	
6/29/2011 10:37	1	39° 14' 30.27616" N	75° 00' 35.52390" W	0.5576	*Spartina alterniflora* (tall)	
6/29/2011 10:38	1	39° 14' 30.65738" N	75° 00' 36.37323" W	0.6784	*Spartina alterniflora* (tall)	
6/29/2011 10:39	1	39° 14' 30.78460" N	75° 00' 37.21096" W	0.7756	*Spartina alterniflora* (tall)	
6/29/2011 10:40	1	39° 14' 30.87150" N	75° 00' 38.05776" W	0.8185	*Spartina alterniflora* (tall)	
6/29/2011 10:41	1	39° 14' 31.05007" N	75° 00' 38.88886" W	0.7971	*Spartina alterniflora* (tall)	
6/29/2011 10:41	1	39° 14' 31.17986" N	75° 00' 39.77542" W	0.7196	*Spartina alterniflora* (tall)	
6/29/2011 10:43	1	39° 14' 31.45752" N	75° 00' 40.61784" W	0.8623	*Spartina alterniflora* (tall)	
6/29/2011 10:44	1	39° 14' 31.86188" N	75° 00' 41.38408" W	0.9048	*Spartina alterniflora* (tall)	
6/29/2011 10:44	1	39° 14' 32.04658" N	75° 00' 42.37148" W	0.8623	*Spartina alterniflora* (tall)	
6/29/2011 10:45	1	39° 14' 32.02826" N	75° 00' 42.56769" W	0.743	*Spartina alterniflora* (tall)	
6/29/2011 10:46	1	39° 14' 31.98486" N	75° 00' 42.71488" W	0.2634	*Spartina alterniflora* (tall)	
6/28/2011 12:20	2	39° 14' 33.74375" N	75° 00' 42.58796" W	0.5357	*Spartina alterniflora* (med)	
6/28/2011 12:22	2	39° 14' 34.46953" N	75° 00' 43.09624" W	0.886	*Spartina alterniflora* (med)	
6/28/2011 12:28	2	39° 14' 34.99641" N	75° 00' 43.65846" W	0.7963	*Spartina alterniflora* (med)	
6/28/2011 12:29	2	39° 14' 34.99739" N	75° 00' 44.53985" W	0.8438	*Spartina alterniflora* (med)	
6/28/2011 12:33	2	39° 14' 35.44762" N	75° 00' 46.08522" W	0.8649	*Spartina alterniflora* (med)	
6/28/2011 12:38	2	39° 14' 36.16303" N	75° 00' 46.68693" W	0.8416	*Spartina alterniflora* (med)	
6/28/2011 12:39	2	39° 14' 36.32741" N	75° 00' 47.09232" W	0.8298	*Spartina alterniflora* (med)	*Distichlis spicata*
6/28/2011 12:40	2	39° 14' 36.42417" N	75° 00' 47.30352" W	0.8342	*Spartina alterniflora* (med)	*Distichlis spicata*
6/28/2011 12:41	2	39° 14' 36.69718" N	75° 00' 48.04431" W	0.8617	*Spartina alterniflora* (med)	
6/28/2011 12:42	2	39° 14' 37.03962" N	75° 00' 48.77488" W	0.8452	*Spartina alterniflora* (med)	
6/28/2011 12:42	2	39° 14' 37.39616" N	75° 00' 49.51084" W	0.8215	*Spartina alterniflora* (med)	
6/28/2011 12:43	2	39° 14' 37.65562" N	75° 00' 50.23010" W	0.6727	*Spartina alterniflora* (med)	

Table 5 con't.

Date/Time	Transect	Latitude	Longitude	Ortho Ht.	Dom Spp	Subdom Spp
6/28/2011 12:45	2	39° 14' 37.88715" N	75° 00' 50.89404" W	0.7424	*Spartina alterniflora* (short)	
6/28/2011 12:46	2	39° 14' 38.19184" N	75° 00' 51.66088" W	0.7247	*Spartina alterniflora* (med)	
6/28/2011 12:46	2	39° 14' 38.56528" N	75° 00' 52.40648" W	0.5671	*Spartina alterniflora* (med)	
6/28/2011 12:47	2	39° 14' 38.74030" N	75° 00' 53.00151" W	0.6641	*Spartina alterniflora* (med)	
6/28/2011 12:51	2	39° 14' 39.13119" N	75° 00' 53.73196" W	0.6428	*Spartina alterniflora* (med)	
6/28/2011 12:52	2	39° 14' 39.45136" N	75° 00' 54.53752" W	0.6128	*Spartina alterniflora* (med)	
6/28/2011 12:53	2	39° 14' 39.67223" N	75° 00' 55.41771" W	0.568	*Spartina alterniflora* (tall)	
6/28/2011 12:54	2	39° 14' 39.84096" N	75° 00' 55.77694" W	0.377	*Spartina alterniflora* (tall)	
6/28/2011 12:54	2	39° 14' 39.84516" N	75° 00' 55.80930" W	0.2971	*Spartina alterniflora* (tall)	
6/28/2011 12:55	2	39° 14' 40.26330" N	75° 00' 56.52752" W	0.5604	*Spartina alterniflora* (med)	
6/28/2011 12:56	2	39° 14' 40.64124" N	75° 00' 57.24390" W	0.8088	*Spartina alterniflora* (med)	*Phragmites australis*
6/28/2011 12:56	2	39° 14' 40.69282" N	75° 00' 57.38691" W	0.2395	*Phragmites australis*	*Spartina alterniflora* (med)
6/28/2011 12:56	2	39° 14' 40.73738" N	75° 00' 57.49417" W	-0.1224	*Spartina alterniflora* (med)	*Phragmites australis*
6/28/2011 12:56	2	39° 14' 40.77891" N	75° 00' 57.61443" W	-0.3015	mud flat	
6/29/2011 9:58	3	39° 14' 31.13627" N	75° 00' 34.86906" W	0.6624	*Spartina alterniflora* (med)	*Phragmites australis*
6/29/2011 10:04	3	39° 14' 31.38836" N	75° 00' 36.06387" W	0.6851	*Spartina alterniflora* (short)	
6/29/2011 10:05	3	39° 14' 31.56869" N	75° 00' 36.93025" W	0.6667	*Spartina alterniflora* (med)	
6/29/2011 10:06	3	39° 14' 31.73435" N	75° 00' 37.80090" W	0.615	*Spartina alterniflora* (med)	
6/29/2011 10:07	3	39° 14' 31.96205" N	75° 00' 38.57977" W	0.6719	*Spartina alterniflora* (med)	
6/29/2011 10:10	3	39° 14' 32.11329" N	75° 00' 38.92721" W	0.6622	*Schoenoplectus robustus*	*Spartina alterniflora* (med)
6/29/2011 10:11	3	39° 14' 32.21714" N	75° 00' 39.26002" W	0.6817	*Spartina alterniflora* (med)	
6/29/2011 10:12	3	39° 14' 32.54358" N	75° 00' 40.07638" W	0.6253	*Spartina alterniflora* (med)	
6/29/2011 10:13	3	39° 14' 32.81180" N	75° 00' 40.81060" W	0.7051	*Spartina alterniflora* (med)	
6/29/2011 10:14	3	39° 14' 33.12910" N	75° 00' 41.59027" W	0.7735	*Spartina alterniflora* (med)	
6/29/2011 10:14	3	39° 14' 33.40766" N	75° 00' 42.29342" W	0.7811	*Spartina alterniflora* (med)	
6/29/2011 10:15	3	39° 14' 33.50284" N	75° 00' 42.42820" W	0.6178	*Spartina alterniflora* (med)	
6/29/2011 10:15	3	39° 14' 33.55590" N	75° 00' 42.48806" W	0.1169	*Spartina alterniflora* (tall)	

Faunal Integrity
Metazoan infauna and epifauna such as burrowing fiddler crabs, large worms and bivalve suspension-feeders were characterized in study plots using established sampling and analysis approaches (e.g., Colby and Fonseca 1984, Grace 1984, Bertness 1985). These analyses of fauna and flora helped ascertain whether typical marsh trophic assemblages were present and sufficiently abundant to perform critical functions such as filtration, degradation/remineralization and trophic services (e.g., Dove and Nyman 1995, Kreeger and Newell 2000). Key invertebrate faunal components (e.g. populations of amphipods, gastropods, etc) involved in the *in situ* decomposition of emergent wetland plants were sampled along with the standing live and dead components of the plant assemblages adjacent to both the terrestrial and aquatic wetland interfaces at each fixed station. The potential response metrics in this research included species richness, size distributions, abundance, brood sizes, and sex ratios (indicator of endocrine disruptors) of invertebrates associated with standing vegetation.

At each monitoring location, six randomly-selected quadrats (1 m2) were established within 5 m marsh edge. Epifaunal macroinvertebrates were identified to species, counted, and measured. A subsample of each species comprising all size classes in the sample were individually (or in small groups) dried and weighed to provide a measure of condition (size-specific mass). These data provided information on spatial and temporal variation in species richness, size distributions, sex ratios and reproductive potential within the decomposer assemblages.

Above- and Belowground Biomass
Once per year at peak biomass (July/August), three plots were established in both low marsh or nearest distance from the main water body and high marsh or farthest distance from the main water body ~10 m landward of each of two of the three SETs eat each monitoring station (Figure 11). Depending on site-specific geomorphology, the two biomass collection areas may have differed in elevation and plant community as well as distance from the water body and sediment source. The three plots were no less than 10 m from any SET-MH. For appropriate consistency and replication, the three plots established near each SET were established in the same or similar plant community. At maximum annual productivity (July/August), aboveground, wrack, and belowground biomass was collected.

Aboveground biomass was harvested within 0.5 m2 quadrats for salt marsh sites and 1.0 m2 quadrats for tidal fresh marsh sites by clipping all standing vegetation at the marsh surface. Aboveground biomass was placed into labeled plastic bags and taken back to the lab for processing. All litter on the marsh surface within the plot area was collected and placed in a labeled bag. Belowground biomass was collected within the center of the clipped plot as a 15-cm diameter x 30-cm depth soil core by pounding a PVC core barrel. The belowground biomass was washed over a 5 mm mesh sieve and separated into live and dead material. All material was washed, dried, ground, and measured for loss on ignition. Samples were stored for biochemical analysis if needed.

Algal biomass

Three soil plugs were collected 10-m landward of SETs 1 and 3 in each wetland monitoring station two to three times per year using a cut stainless steel pipe (2.5 cm diameter x 2.5 cm depth). The top 1cm depth was sectioned and processed for measurement of chl *a*. Samples were stored on ice in the field and in the freezer in the lab until processed. Approximately 0.2000g of homogenized sediment was weighed into acid washed glass vials. Each sample was done in duplicate. 10 mL of 90% acetone was added and vials were capped and stored in at 4C for 48 hours. Vials were inverted at least ten times during the cooling period. Depending on concentration of chl-a in solution 2ml to 0.5ml of solution was pipetted into a glass cuvet with the associated amount of 90% acetone to equal 7mL in total. Samples were inverted 3 times and run on a Turner TD-700 Fluorometer. Each vial was run in duplicate. Results were calculated using a calibration curve previously made with a Chlorophyll-a standard, free of b and c forms (Sigma Chemicals).

Soil Carbon and Nutrients

Soil cores (10-cm diameter x 20-cm depth) were collected adjacent to the plots established for biomass sampling. Soil organic content and quality (% carbon, nitrogen, and phosphorus and LOI) was determined for the mid-point of 3 depth intervals of 0 – 10, 10- 20, and 20 – 30 cm. To distinguish between inorganic and organic matter deposition the percent loss on ignition is being determined by placing samples in a muffle furnace at 450°C for 8 hours. Total organic carbon and total nitrogen were measured using a CE Flash Elemental Analyzer following the guidelines in EPA 440.0, manufacturer instructions and ANSP-PC SOP. Samples were pre-treated with acid to remove inorganic carbon.

Water chemistry

Five points were established along the nearest main channel or tidal creek for spot measurements using an YSI Model 556 and water collection. Specific locations in tidal creeks (upper, mid, and lower) in each of the four wetland monitoring sites were designated for water quality assessment (Table 6). Spot measurements included temperature, conductivity, dissolved oxygen, and depth (YSI meter).

Tidal creek surface water samples were collected, filtered, and analyzed for dissolved and particulate nutrients. Sampling and data collection occurred approximately two hours after high tide (i.e., during ebb tide). One gallon cubitainers were rinsed with site water and then filled at each of the five locations along the main water body / tidal creek. Cubitainers were stored on ice in the dark while in the field. Water samples were analyzed for total suspended solids, suspended Chlor *a* (fluorometric; acidification method), dissolved ammonium+ammonia, dissolved nitrate+nitrite, soluble reactive phosphorus, dissolved organic carbon, total nitrogen (TKN+Dissolved nitrate+nitrite), and total phosphorus.

Table 6. Location of water collections stations in wetland monitoring sites.

Estuary	Site	Plot #	Lat	Long
Delaware Bay	Tinicum	1	39°53'5.10"N	75°15'55.40"W
		2	39°52'58.10"N	75°16'2.60"W
		3	39°52'54.90"N	75°16'7.00"W
		4	39°52'5.10"N	75°16'27.50"W
		5	39°52'38.30"N	75°17'49.70"W
	Christina	1	39°43'20.21"N	75°33'35.46"W
		2	39°43'13.79"N	75°33'39.64"W
		3	39°43'8.53"N	75°33'47.11"W
		4	39°43'5.51"N	75°34'0.02"W
		5	39°43'7.33"N	75°34'53.94"W
	Maurice	1	39°14'45.93"N	75° 0'44.11"W
		2	39°14'48.05"N	75° 0'58.80"W
		3	39°14'36.51"N	75° 1'5.52"W
		4	39°14'28.01"N	75° 0'57.22"W
		5	39°14'21.76"N	75° 0'42.34"W

Results

Three SSIM stations were installed at Tinicum, Christina, and Maurice study marshes, and then preliminary monitoring data were collected during 2010 – 2011 as summarized in Table 7. These measurements included SET readings, line transects, biomass, plant community, faunal integrity, and soil and water quality (Table 2-6). In most cases, SET arrays were along a single line (Fig. 6) and therefore the line transects were conducted in three parallel lines from the water's edge to 25 m beyond the final SET (SET3) (Fig. 11). Below we summarize experiences and data for each of the three stations.

Table 7. Dates of installation and monitoring for various SSIM metrics at the three study marshes, 2010-2011.

Site	Install SET	MH install	SET Reading	Line Transect	Soil Cores	Water Chemistry
Tinicum, PA	7/20/10	3/12/11	3/12/11, 8/30/2011, 10/4/11	8/5/11	5/12/2011, 8/4/11	9/7/10, 10/18/10, 3/12/11, 8/8/11
Christina, DE	9/17/10	3/15/11	3/15/11, 9/1/11	7/13/11	11/8/10, 3/15/11	9/3/10, 11/8/10, 2/6/10, 9/1/11
Maurice, NJ	10/13/10	4/18/11	4/18/11, 9/20/11	6/28/11	4/18/11, 9/20/11	4/18/11, 9/20/11

Tinicum

Pictures of various field activities at the Tinicum Station are pictured in Figure 12. Surface elevation tables were installed at the Tinicum tidal freshwater wetland monitoring station on July 20, 2010 (Table 7). Initial SET readings were collected on March 12, 2011 when feldspar marker horizons were established within 5 m of each SET. Subsequent SET readings occurred on August 30 and October 4, 2011, when a demonstration of the cryo-coring technique for collecting MH data was implemented by Jim Lynch of the National Park Service. During the first time interval, the surface elevation change was +13.5 ± 2.0 mm (Fig. 13). From August to October, the surface elevation change was +11.93 ± 7.93 mm with a total elevation increase over the 206 days of measurement of 25.5 mm. Based on the two data points, an annual growth rate averaged over the three SETs would be ~39.8 mm yr-1, however because there was only two points the relationship is not significant ($y = 39.8x – 0.75$, $r2 = 0.90$, $p = 0.2089$).

Figure 12. Pictures of various field activities at Tinicum over 2010 through 2011

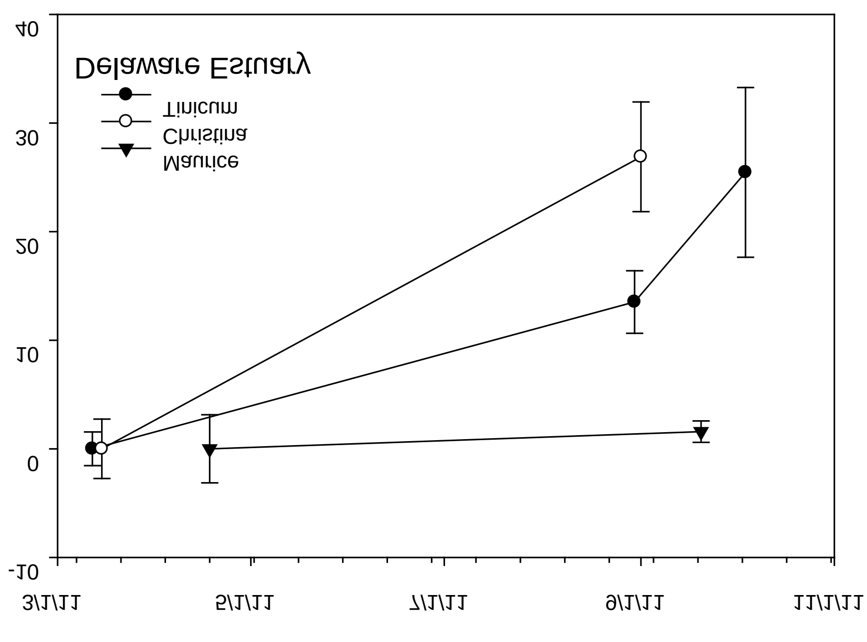

Figure 13. Initial surface elevation changes (millimeters) measured using SETs in three wetlands of Delaware Bay, two tidal freshwater wetlands at Tinicum and Christina and one salt marsh at Maurice (n = 3, ± s.e.).

Line transects were surveyed in Tinicum on August 5, 2011. Elevations ranged from -0.82 to 0.88 m (NAVD88) (Table 3). Dominant species along transects included *N. lutea*, *Z. aquatica*, *P. virginica*, *Sagittaria latifolia*, and *Pontedaria chordata*. *Nuphar lutea* had the highest frequency in the permanent and random edge vegetation plots (Table 8). Permanent plots had six species and random edge plots had a total of five species present. Percent cover averaged 66% in permanent plots and 94% in random edge plots (Table 8). *Zizania aquatica* and *Typha angustifolia* were among the tallest plant species in plots (Table 8). Light intensity was approximately 200 lx at the bottom of the canopy in both permanent and random plots (Fig. 14).

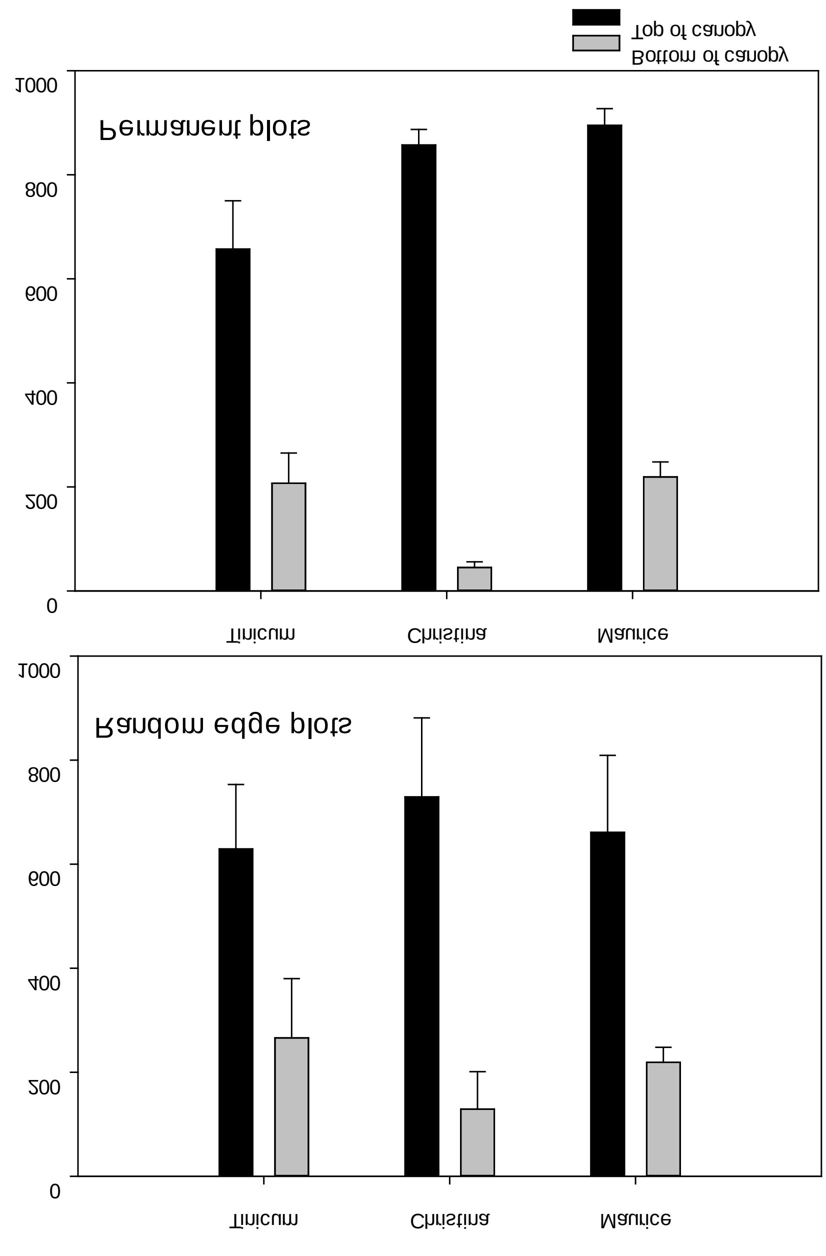

Figure 14**.** Light intensity above- and below the plant canopy in permanent and random edge plots in mid-summer 2011.

Table 8. Species cover and height in permanent (n = 9) and random edge (n = 6) vegetation plots in the three wetland monitoring sites in mid-summer 2011. Values are means ± standard errors.

Site	Plot	Species	*n*	Percent cover	Average height (cm)
Tinicum	Permanent	*Nuphar lutea*	6	34 ± 4	68 ± 7
		Typha angustifolia	4	10 ± 2	139 ± 18
		Zizania aquatica	4	30 ± 5	206 ± 28
		Peltandra virginica	3	37 ± 14	79 ± 16
		Pondeteria cordata	3	22 ± 6	120 ± 16
		Sagittaria latifolia	2	25 ± 5	103 ± 7
	Random edge	*Nuphar lutea*	5	80 ± 20	92 ± 8
		Typha angustifolia	2	37 ± 7	218 ± 57
		Polygonum hydropiperoides	2	3 ± 1	131 ± 69
		Phragmites australis	1	40	274
		Impatiens capensis	1	40	80
Christina	Permanent	*Typha angustifolia*	9	47 ± 5	247 ± 9
		Peltandra virginica	9	23 ± 4	128 ± 5
		Impatiens capensis	4	10 ± 4	121 ± 18
		Nuphar lutea	2	25 ± 24	112 ± 34
		Sagittaria latifolia	1	15	135
		Polygonum hydropiperoides	1	1	-
		Persicaria perfoliata	1	1	-
		Lonicera sempervirens	1	40	-
		Parthenocissus quinquefolia	1	5	-
	Random edge	*Nuphar lutea*	4	46 ± 18	97 ± 7
		Pontedaria cordata	4	34 ± 16	134 ± 10
		Polygonum hydropiperoides	2	12 ± 7	114 ± 9
		Impatiens capensis	1	15	124
		Peltandra virginica	1	40	101
		Ambrosia cumanensis	1	2	131
		Scirpus fluviatilis	1	2	135
		Typha angustifolia	1	35	205
		Zizania aquatica	1	20	208
Maurice	Permanent	medium *Spartina alterniflora*	5	77 ± 6	80 ± 7
		tall *Spartina alterniflora*	3	33 ± 17	88 ± 4
		Phragmites australis	3	30 ± 8	106 ± 6
		short *Spartina alterniflora*	1	90	99
		sedge	1	10	121
	Random edge	tall *Spartina alterniflora*	5	63 ± 7	79 ± 13
		Phragmites australis	1	-	59
		short *Spartina alterniflora*	1	75	91

Aboveground live biomass collected > 10m landward of SETs 1 and 3 averaged 148 and 507 g m-2, respectively (Fig. 15). The vegetation adjacent to SET 1 was dominated by *Nuphar lutea* while the dominant plant species near SET 3 was *T. angustifolia*. *Typha* biomass was highly variable and thus no differences were found between the live biomass at SETs 1 and 3. Dead biomass was over an order of magnitude greater at SET 3 than at SET 1 ($p = 0.0002$).

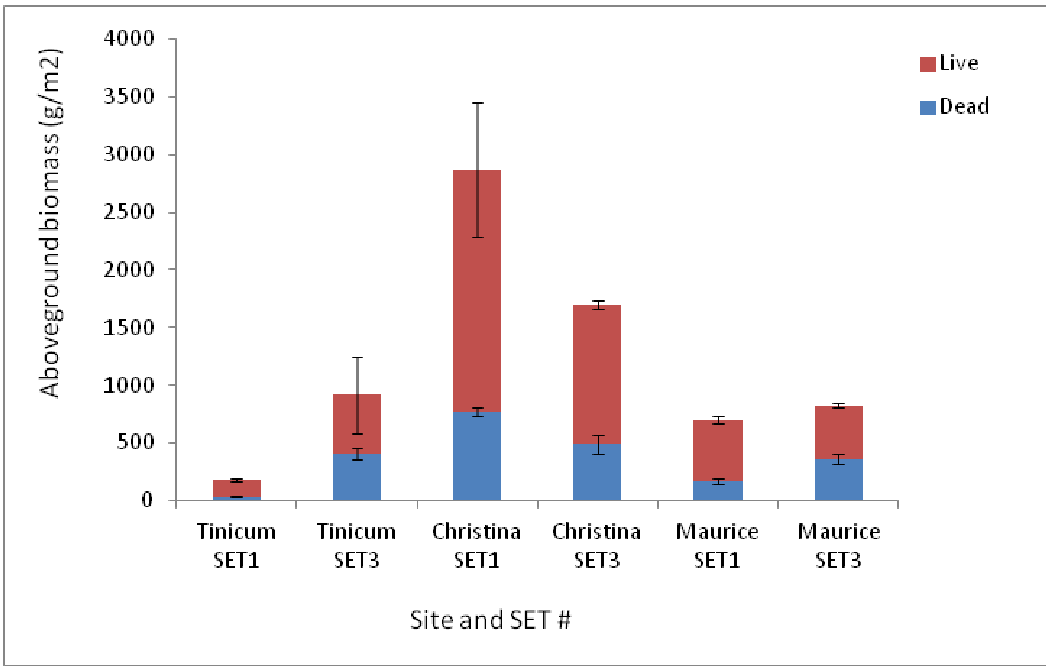

Figure 15. Aboveground live and dead biomass of plants growing near SETs 1 and 3 in Tinicum, Christina, and Maurice in July/August 2011 (n = 3, ± se).

Soil cores were collected >10m landward of SETs 1and 3 on May 12 and August 4, 2011. Averaged across time periods surface (5cm depth) organic matter (OM) content averaged 25% (Table 9). Soil cores had similar organic matter, organic carbon and nitrogen contents among seasons. Spatial variation in soil organic matter, carbon and nitrogen existed with all being significantly greater in around SET 3 than SET 1 ($p < 0.0001$). SET 3 is higher in elevation than SET 1 and the plant community at SET 3 is dominated by *T. angustifolia* while the SET 1 area is dominated by *Nuphar lutea*. The difference in elevation and therefore plant community is likely contributing to difference in soil OM, C and N content. The soil near SET 3 had significantly greater OM, C, and N at the surface (5 and 15cm depths) than at 25 cm ($p=0.0037$, $p=0.0038$, and $p = 0.0007$, respectively). Soil surface chl a was collected adjacent to soil core collection plots. Averaged between the two SET locations, concentrations at Tinicum were 15 $\mu g\ g^{-1}$ in May 2011 (Fig. 16).

Table 9. Soil organic matter, organic carbon, and nitrogen percentages at three depths collected from two locations near (SET 1) and far (SET 3) from the main tidal channel at three wetland monitoring sites in the Delaware Estuary (n = 3, ± s.e.).

			Organic matter (%)			Organic carbon (%)			Nitrogen (%)		
			Depth (cm)			Depth (cm)			Depth (cm)		
Site	Date	SET	5	15	25	5	15	25	5	15	25
Tinicum	5/12/2011	1	16.7 ± 2.2	13.0 ± 0.6	14.7 ± 0.3	6.6 ± 0.8	5.3 ± 0.1	6.7 ± 0.4	0.4 ± 0.03	0.3 ± 0.01	0.3 ± 0.01
		3	33.2 ± 1.9	31.0 ± 3.1	21.2 ± 1.8	15.5 ± 1.8	15.1 ± 1.6	8.9 ± 0.7	0.9 ± 0.11	0.8 ± 0.05	0.5 ± 0.05
	8/4/2011	1	14.8 ± 0.9	14.9 ± 0.7	16.0 ± 1.2	6.0 ± 0.4	7.2 ± 1.0	7.9 ± 1.1	0.4 ± 0.04	0.4 ± 0.04	0.4 ± 0.05
		3	28.3 ± 2.7	31.0 ± 3.6	21.7 ± 3.5	12.5 ± 1.5	16.9 ± 3.4	9.3 ± 1.5	0.8 ± 0.09	0.7 ± 0.07	0.5 ± 0.06
Christina											
	11/8/2010	1	18.4 ± 2.3	16.7 ± 2.0	14.8 ± 1.2	6.3 ± 1.1	5.5 ± 0.9	5.0 ± 0.6	0.4 ± 0.06	0.3 ± 0.05	0.3 ± 0.03
		3	26.7 ± 1.5	32.6 ± 2.5	21.5 ± 1.1	10.7 ± 0.8	13.5 ± 1.1	7.6 ± 0.4	0.6 ± 0.01	0.6 ± 0.09	0.4 ± 0.02
	3/15/2011	1	13.9 ± 0.7	13.9 ± 0.8	13.1 ± 0.2	4.4 ± 0.3	4.4 ± 0.3	4.4 ± 0.2	0.3 ± 0.01	0.2 ± 0.02	0.2 ± 0.01
		3	18.9 ± 1.6	15.9 ± 1.4	14.6 ± 0.7	6.5 ± 0.8	5.3 ± 0.7	4.6 ± 0.1	0.4 ± 0.04	0.3 ± 0.04	0.3 ± 0.01
	9/1/2011	1	17.9 ± 2.1	15.8 ± 0.4	14.6 ± 1.0	6.5 ± 1.1	7.1 ± 1.2	6.0 ± 1.1	0.4 ± 0.05	0.3 ± 0.01	0.3 ± 0.04
		3	32.1 ± 1.6	34.8 ± 10.2	21.3 ± 1.3	13.8 ± 1.2	15.7 ± 5.4	8.7 ± 0.8	0.7 ± 0.04	0.7 ± 0.2	0.4 ± 0.03
Maurice											
	4/18/2011	1	19.0 ± 1.4	18.0 ± 1.1	19.4 ± 0.7	6.0 ± 0.6	5.1 ± 0.3	6.0 ± 0.6	0.4 ± 0.01	0.3 ± 0.00	0.3 ± 0.01
		3	20.7 ± 2.2	18.8 ± 1.0	17.4 ± 0.3	8.3 ± 2.5	8.5 ± 1.5	5.3 ± 0.4	0.4 ± 0.03	0.4 ± 0.06	0.4 ± 0.04
	9/20/2011	1	23.9 ± 5.6	15.6 ± 1.2	15.4 ± 1.8	7.5 ± 1.4	6.2 ± 0.2	6.3 ± 0.2	0.4 ± 0.03	0.4 ± 0.00	0.4 ± 0.01
		3	20.7 ± 2.6	18.5 ± 0.2	13.0 ± 0.1	8.9 ± 1.6	6.6 ± 0.2	5.8 ± 0.7	0.5 ± 0.04	0.4 ± 0.01	0.4 ± 0.01

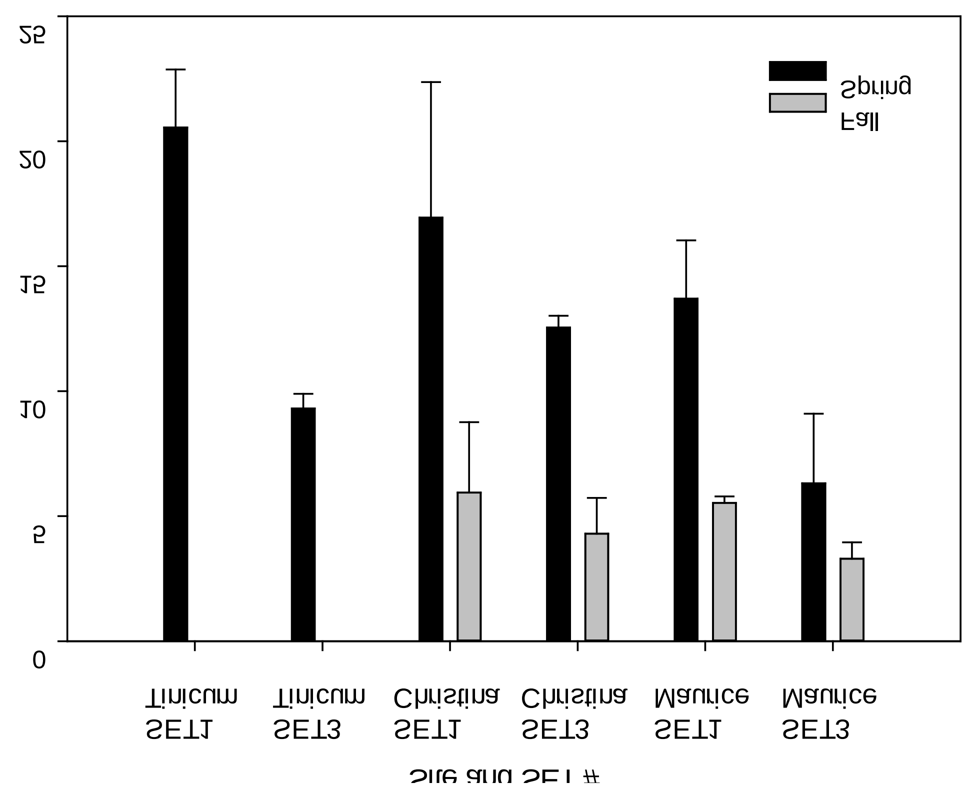

Figure 16**.** Soil surface Chl a in wetlands of the Delaware Bay. Values are means ± standard errors (n = 3).

Water chemistry was measured on 9/7/2010, 10/18/2010, 3/12/2011, and 8/8/2011. Temperature, conductivity, and dissolved oxygen in Darby Creek varied predictably among seasons (Table 10) with a lower temperature in the spring than in the fall months. Future data collection and analyses will be needed to tease out the variation in fall conductivity and percent DO among years, which are likely due to variation in freshwater flow. Total suspended solids averaged across time periods were similar to the Christina River and significantly less than Maurice ($p < 0.0001$; Fig. 17). Nitrate+nitrite-N concentration was similar to Christina and significantly greater than the Maurice ($p < 0.0001$; Fig. 18). Ammonium-N concentration was similar to the other sites in the Delaware Estuary (Fig. 19).

Table 10. Tidal creek surface water properties collected using an YSI meter at Tinicum, Christina and Maurice in Delaware Bay. Values are means ± standard error (n = 5).

Site	Date	Temperature (°C)	Conductivity (µs/cm3)	Dissolved oxygen (%)
Tinicum	9/7/2010	26.3 ± 0.1	633 ± 3	99.2 ± 3.0
	3/12/2010	16.9 ± 0.4	305 ± 10	87.9 ± 2.6
	8/8/2011	21.6 ± 0.3	199 ± 6	61.7 ± 5.2
Christina	9/3/2010	26.9 ± 0.0	2883 ± 121	83.6 ± 0.4
	11/1/2010	11.1 ± 0.7	222 ± 43	79.1 ± 1.3
	2/16/2011	3.1 ± 0.0	787 ± 27	38.1 ± 1.2
Maurice	4/18/2011	12.8 ± 0.1	15403 ± 198	79.7 ± 0.9
	9/20/2011	19.7 ± 0.02	4267 ± 256	69.8 ± 0.6

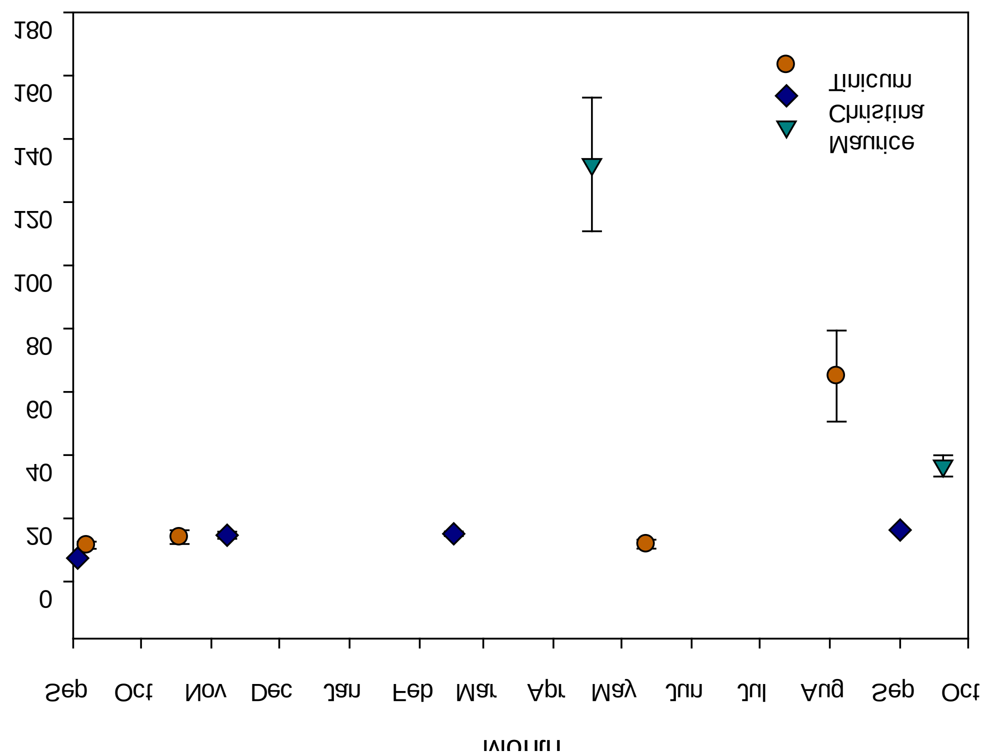

Figure 17**.** Total suspended solids in tidal creek or estuary water in two tidal freshwater wetlands, Tinicum and Christina, and one salt marsh, Maurice in the Delaware collected in 2010 – 2011 (n = 5, ± s.e.).

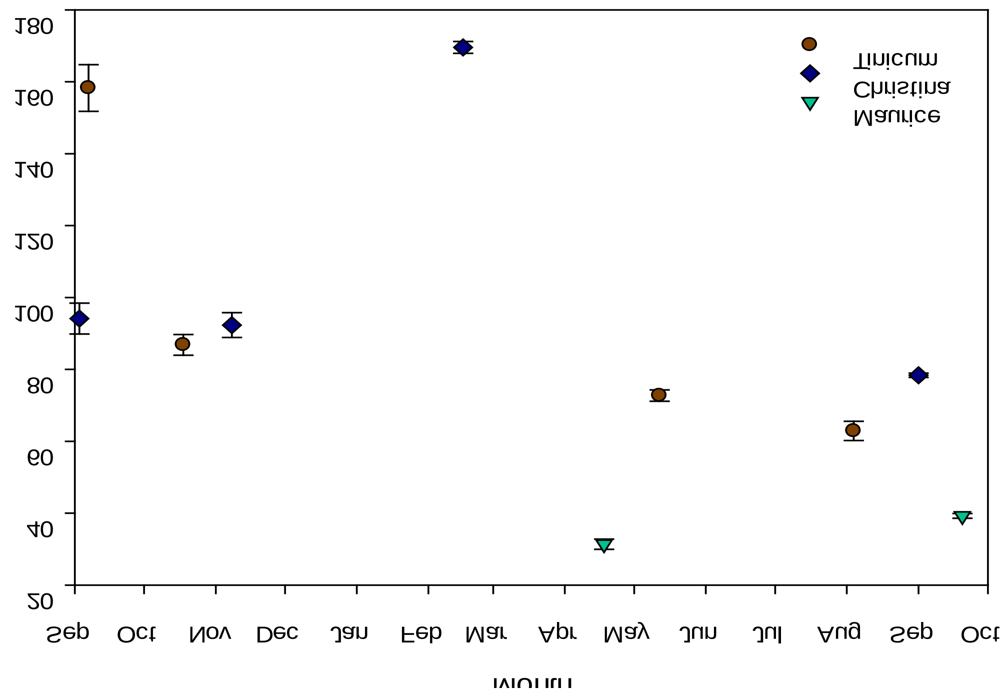

Figure 18. Nitrate+nitrate nitrogen concentrations in tidal waters of wetland monitoring sites of the Delaware Estuary from spot samples collected 2010 – 2011. Values are means (n = 5, ± s.e.).

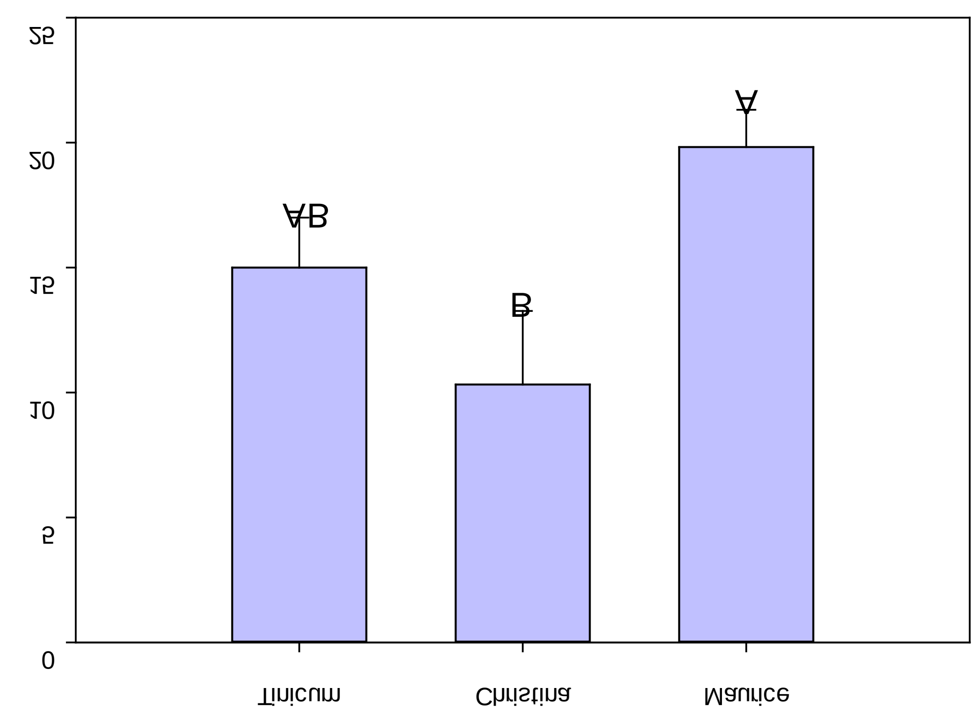

Figure 19. Ammonium nitrogen concentrations in tidal waters of wetland monitoring sites of the Delaware Estuary. Values are means, averaged over time (n = 5, ± s.e.).

Christina River

Pictures of various field activities at the Christina Station are pictured in Figure 20. Surface elevation tables were installed at the Tinicum tidal freshwater wetland monitoring station on September 17, 2010 (Table 7). Baseline SET readings occurred on March 15, 2011 when feldspar marker horizons were established within 5 m of each SET. Subsequent SET readings occurred on September 1, 2011 after 170 days. Surface elevation change over the 170 days was +26.9 ± 5.0 mm (Fig. 13).

Figure 20. Pictures of various field activities at the Christina station during 2010 and 2011.

Line transects were surveyed at the Christina River station on July 13, 2011. Minimum elevation along transect was 0.43 m and maximum elevation was 1.0 m. Dominant species included *Typha angustifolia*, *P. virginica*, *Impatiens capensis*, and *Scirpus fluviatilis*. Nine species were found in permanent and random edge plots including low frequencies of weedy species (Table 8). *Typha angustifolia* and *P. virginica* were the most frequent species, found in 100% of the permanent plots. The random edge plots were dominated by *N. lutea* and *P. cordata*. Light level at the bottom of the canopy was particularly low in permanent plots (Fig. 14), which had *T. angustifolia* contributing to 47% of the vegetative cover. Aboveground biomass was variable at

SET 3 such that significant differences between biomass at SET 1 and 3 were not detected (Fig. 15). Average live biomass at Christina was 1653 g/m2 similar to the quantity of dead biomass.

Soil cores were collected >10m landward of SETs 1 and 3 on November 8, 2010, March 15 and September 1, 2011. Averaged across time periods surface (5cm depth) organic matter (OM) content averaged 23% (Table 9). Cores at SET 3 collected in March 2010 had significantly less OM, C and N contents than cores collected in November 2010 and September 2011. Future sampling will allow us to determine whether the seasonality is real or if it was a function of spatial variation near SET 3. Soil organic matter, carbon, and nitrogen content were significantly greater near SET 3 than SET 1 ($p < 0.0001$). Soil OM, C, and N were similar among the 5, 15, and 25 cm depths at both SETs 1 and 3. Soil surface chl a was collected adjacent to soil core collection plots. Averaged between the two time periods chl a concentrations at Christina were 14.7 µg g-1 (Fig. 16). Chl a concentration on the marsh surface was greater in the spring than the fall.

Water chemistry was measured on 9/3/2010, 11/8/2010, 2/6/2010, and 9/1/2011 (Table 10). Total suspended solids averaged across time periods significantly less than at salt marsh sites within the Delaware Estuary (Fig. 17). Nitrate+nitrite-N concentration was similar to Tinicum and significantly greater than the Maurice River (Fig. 18). Ammonium-N concentration was significantly less at Christina River than the Maurice River (Fig. 19).

Maurice River

Pictures of various field activities at the Christina Station are pictured in Figure 21. Surface elevation tables were installed at the Maurice River salt marsh monitoring station on October 13, 2010 (Table 7). Baseline SET readings at Maurice occurred on April 18, 2011 when feldspar marker horizons were established within 5 m of each SET. A second round of SET readings was taken 155 days later on September 20, 2011. Surface elevation change was +1.58 ± 0.99 over the time period (Fig. 13).

Line transects and permanent and random vegetation plots were established in Maurice on June 28, 2011. Elevation along transects ranged from -0.37 to 0.90 m with the plant community dominated by medium form *S. alterniflora* (Table 8). Three height forms were found in permanent vegetation plots, with the medium height form being the most frequent and contributing to approximately 77% of the plant cover (Table 8). Along the edge the tall form of *S. alterniflora* was dominant. Aboveground live biomass collected > 10m landward of SETs 1 and 3 was primarily short and medium forms of *S. alterniflora* and averaged 497 g m-2 (Fig. 15). Live biomass was similar between SETs 1 and 3 but dead biomass was almost two times greater at SET 3 than SET 1 ($p = 0.0240$).

Ribbed mussels (*Geukensia demissa)* were found in four of the six random edge vegetation plots. Mussel density ranged from 1 to 5 individuals per square meter. Fiddler crabs or *Uca spp*. was found in some edge plots and were taken back to the lab for further identification. In three out of nine permanent vegetation plots, individual *Melampus bidentatus* or common marsh snail was found.

Figure 21. Pictures of various field activities at the Maurice station during 2010 and 2011.

Soil cores were collected >10m landward of SETs 1and 3 on April 18 and September 20, 2011. Averaged across time periods surface (5cm depth) organic matter (OM) content averaged 20% (Table 9), similar to the tidal freshwater wetlands but significantly less than the salt marsh at Dennis Creek, NJ to the southeast. While the plant community was dominated by the same species, *Spartina alterniflora* and soil organic matter and carbon content were similar near SETs 1 and 2, soil N was significantly greater near SET 3 (0.43%) than near SET 1 (0.35%) across seasons and depths ($p = 0.0021$). Interestingly, soil organic matter content was significantly lower at 25 cm depth (15%) than at 5 cm depth (21%) at SET 3 only. Soil surface chl a was collected adjacent to soil core collection plots. Averaged between the two time periods in April and September chl a concentrations at Maurice averaged 10 µg g^{-1} (Fig. 16). In the fall, Chl *a* concentrations tended to be lower and less variable than in the spring.

Water chemistry was measured on 4/18//2011 and 9/20/2011 (Table 10). Total suspended solids averaged across time periods were variable and significantly greater than a tidal fresh water sites within the Delaware Estuary and greater than other salt marsh sites in Barnegat Bay, NJ (Fig. 17). Nitrate+nitrite-N concentration was significantly greater in the Maurice River than in Dennis Creek and significantly less than in the tidal fresh water marshes in the upper estuary (Fig. 18). Ammonium-N concentration was significantly greater at Maurice than the other salt marsh site at Dennis and the tidal freshwater Christina River (Fig. 19).

Site comparisons and summary

Tinicum wetland is located along Darby Creek, a tributary to the Delaware Estuary south of Philadelphia, PA. Tinicum wetland experiences a tidal range averaging 1.8 m. Elevations based on line transects ranged from -0.82 to 0.88 m and averaged 0.25 m (NAVD88). The wetland site along the Christina River in Wilmington, Delaware experiences a tidal range of approximately 1.5 m and sits at a higher elevation than Tinicum with a range of 0.43 to 1.0 m and an average of 0.63 m. Thus the dominant plant community of Tinicum is adapted to lower marsh habitats, such as *N. lutea* than the plant community of the Christina, which is dominated by higher marsh species, *T. angustifolia*. The salt marsh along the Maurice River occurs along a relatively large meandering tributary to the Delaware Bay along the New Jersey Bay shore. The salt marsh site along the Maurice experiences a tidal range of over 1 m and has an elevation between that of Tinicum and Christina averaging 0.5951 m and ranging from -0.38 to 0.90 m. Maurice is dominated by short and medium forms of *S. alterniflora*.

Surface elevation changes were similar between the two tidal freshwater wetlands, which had greater accretion rates than the salt marsh at Maurice. A faster rate of accretion in tidal freshwater wetlands than salt marshes is expected associated with higher rates of mineral sedimentation from nearer riverine sources, and slower rates of organic matter decomposition (methane production pathway rather than sulfate reduction pathway).

Interestingly, the same species were shorter at Tinicum than at Christina. For example, average stem height of *T. angustifolia* was 139 cm at Tinicum but 247 at Christina. Similarly, *P. virginica* averaged 79 cm at Tinicum and 128 cm at Christina, where it was more abundant. Average biomass aboveground tended to be greater at Christina, particularly near the channel, although with high variability. This was associated with species differences with Christina biomass dominated by *T. angustifolia* and Tinicum biomass dominated by *N. lutea*, near SET 1. Maurice biomass (medium *S. alterniflora*) was similar to that of the *T. angustifolia* biomass near SET 3 at Tinicum and greater than that of the *N. lutea* biomass near SET 1.

Tidal freshwater wetlands at Tinicum and Christina had similar soil organic matter contents to the salt marsh along the Maurice River. Soil organic carbon content was significantly greater at Tinicum (10%) than at Maurice (6%) across depths and seasons ($p < 0.0001$). Tinicum also had greater soil N (0.5%) than Christina (0.4%) ($p < 0.0001$). Algal biomass on the soil surface measured as Chl *a* concentration tended to be greater in the spring than the fall at all sites and also tended to be less at SET 3 than SET 1 at all sites associated with a farther distance from the water and possibly plant canopy cover and light availability at the surface.

Nutrient concentrations were generally high in the upper estuary, which may be expected due to the urbanized watershed. Somewhat surprising was the high concentration of ammonium-N in the Maurice River, which was higher than the concentrations found in the urban tidal freshwater marshes. The high ammonium concentration at Maurice may be due to sewage treatment effluent farther upstream.

In summary, the first year of SSIM data collection revealed some stark spatial differences in important physical, chemical and biological conditions among the study marshes as well as within some marshes. Most notably, different elevations and plant communities occurred between the two tidal freshwater marshes, and as expected important differences in accretion and plant community were found between the tidal fresh and salt marsh sites. ***If sustained, continued monitoring of these core SSIM metrics at these stations will enable significantly greater insights into the reasons for these differences, and the implications for marsh function and fates.*** This is especially true for surface elevation and accretion measurements, which are widely regarded as requiring long monitoring timespans to accumulate increasingly more valuable data.

Rapid Assessment Methods (RAM)

There are various rapid assessments that have been developed around the nation, but none had incorporated the distinctive tidal wetlands of the mid-Atlantic region. The Delaware Department of Natural Resources and Environmental Control (DNREC) in the early 2000's looked to acquire a better understanding of the health of their wetlands which would help dictate how the state could restore and protect the remaining wetlands. Drawing from the New England Rapid Assessment Method (NERAM) and the California Rapid Assessment Method (CRAM) and working with the Maryland Department of Natural Resources and the Virginia Institute of Marine sciences a Mid-Atlantic Tidal Rapid Assessment Method (Mid-TRAM) was developed.

The original Mid-TRAM protocol was developed using data collected in the Indian River watershed (DE), Nanticoke watershed (MD) and York watershed (VA) in 2006 and 2007. Numerous metrics were included in the first version of Mid-TRAM, drawing from local experiences in these watersheds, as well as from the NERAM, CRAM and other metrics that were though could be useful. Based on the data, analysis metrics were chosen that proved to be the most appropriate to the mid-Atlantic region. Since the first version of the Mid-TRAM, DNREC has continued to improve the metrics in Mid-TRAM based on lessons learned from accumulating experiences and data. Some metrics have been added and some removed.

At the time when this project was first beginning, DNREC had developed a second version of Mid-TRAM, and this is the version that we used (see QAPP, Appendix A). Mid-TRAM v.2 assesses wetland health by scoring various metrics within each of three components: buffers, hydrology and biology (see below and Appendix A). Subsequent to initiating our work using Mid-TRAM v.2 and following extensive field testing, we further modified Mid-TRAM v.2 to include a fourth attribute, shoreline condition (see below). The addition of the fourth attribute and further refining of metrics in the other three metrics went into Mid-TRAM v.3.

At present, we collect data for Mid-TRAM v.3 for all four attributes, and then decide whether to include the shoreline attribute based on analysis goals. For example, in comparisons with existing data from MACWA or DNREC where only three attributes were assessed, we only calculate RAM scores for the three attributes. In contrast, analyses designed to assess conditions at only one study watershed or in relation to sea level rise stress, where appropriate we include all four metrics.

Methods

The current version of the Mid-TRAM that was adapted by PDE (i.e., Mid-TRAM v.3) captures four attributes that are important to tidal wetlands; habitat and biotic community, hydrology, buffer, and shorelines (Table 11). In general, the buffer attribute considers stressors or migration impediments on the landward side of a sample point assessment area, whereas the shoreline attribute considers stressors such as erosion or hardening on the seaward side of a sample point assessment area. The hydrology attribute looks at anthropogenic changes to the hydrology within the wetland including ditching and fill. The habitat attribute attempts to capture aboveground and belowground biomass estimates, plant communities and invasive cover.

Within each attribute there are multiple metrics. Each metric is given a score between 3 and 12 and then combined with the other metrics in that attribute as a percentage of the total possible value for that attribute. The value is adjusted to a 0-100 scale. The attributes are then averaged to provide a composite Mid=TRAM score.

Mid-TRAM v.2:
Buffer= ((((Σ(B1…B5))/60)*100)-25)/75)*100
Hydrology= ((((Σ(H1…H4))/48)*100)-25)/75)*100
Habitat= ((((Σ(HAB1…HAB5))/60)*100)-25)/75)*100
MidTRAM v.2 score = ((Buffer + Hydrology + Habitat)/3)

Mid-TRAM v.3:
Buffer= ((((Σ(B1…B5))/60)*100)-25)/75)*100
Hydrology= ((((Σ(H1…H4))/48)*100)-25)/75)*100
Habitat= ((((Σ(HAB1…HAB5))/60)*100)-25)/75)*100
Shoreline = ((((Σ(S1…S2))/24)*100)-25)/75)*100
MidTRAM v.3 score = ((Buffer + Hydrology + Habitat + Shoreline)/4)

The latest version of Mid-TRAM that is used by DNREC can be accessed online at; http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Pages/Wetland-Monitoring-and-Assessment.aspx and the current version used by PDE for MACWA can be accessed at: http://www.delawareestuary.org/science_stac_workgroups_wetlands_products.asp. Please refer to the QAPP for full details on the methods used in this study (Appendix A).

It takes approximately two to three people, one to two hours to perform the MID-TRAM at a particular sample point, once it has been reached. In tidal wetlands, the stage of tide, logistics, and time to get to sites also needs to be taken into effect. Often, approximately 2 sites can be completed per day.

The Mid-TRAM should be completed for at least 30 sites per study watershed to allow sufficient coverage and sample density for a representative assessment of that watershed's wetland health. Sites are determined using a probabilistic method. The array of points are determined for each watershed with the help of US EPA's Western Ecology Division, and their environmental statisticians Anthony (Tony) R. Olsen. A Generalized Random Tessellation Stratified (GRTS) survey design for an aerial resource is used. The GRTS design included reverse hierarchical ordering of the selected sites. This layer was developed from the National Wetlands Inventory Maps that were clipped to the tidal watersheds. This layer can be found on the

National Wetlands Inventory website at: http://www.fws.gov/wetlands/Data/DataDownload.html.

Table 11. Attributes and Metrics of the PDE-modified version of Mid-TRAM v. 3.0.

Attribute	Metric	Description
Buffer/Landscape	Percent of AA Perimeter with 5m- Buffer	Percent of AA perimeter that has at least 5m of natural or semi-natural condition land cover
Buffer/Landscape	Average Buffer Width	The average buffer width surrounding the AA that is in natural or semi-natural condition
Buffer/Landscape	Surrounding Development	Percent of developed land within 250m from the edge of the AA
Buffer/Landscape	250m Landscape Condition	Landscape condition within 250m surrounding the AA based on the nativeness of vegetation, disturbance to substrate and extent of human visitation
Buffer/Landscape	Barriers to Landward Migration	Percent of landward perimeter of wetland within 250m that has physical barriers preventing wetland migration inland
Hydrology	Ditching & Draining	The presence of ditches in the AA
Hydrology	Fill & Fragmentation	The presence of fill or wetland fragmentation from anthropogenic sources in the AA
Hydrology	Wetland Diking / Tidal Restriction	The presence of dikes or other tidal flow restrictions
Hydrology	Point Sources	The presence of localized sources of pollution
Habitat	Bearing Capacity	Soil resistance using a slide hammer
Habitat	Vegetative Obstruction	Visual obstruction by vegetation <1m measured with a cover board.
Habitat	Number of Plant Layers	Number of plant layers in the AA based on plant height
Habitat	Percent Co-dominant Invasive Species	Percent of co-dominant invasive species in the AA
Habitat	Percent Invasive	Percent cover of invasive species in the AA
Shoreline	Shoreline Erosion	Shoreline condition at shoreline transect points based on the erosion:accretion ratio
Shoreline	Shoreline Alteration	Presence of built structures or non-natural materials along the shoreline at transect points

The targeted sample frame for MACWA consists of emergent vegetated tidal wetlands, therefore the NWI wetland coverage layers had to be clipped to remove non-vegetated wetlands and non-tidal wetlands from the original layer. The NWI Cowardin classifications that were deleted are listed in Table 12.

Table 12. Cowardin wetland classes that were removed from GIS layers used to drop sample points for MACWA RAM>

Class equal to:	NWI/Cowardin Description
P*	Palustrine- except those with *R,*S,*T,*V
L*	Lakes and millponds
R1UBL	Riverine Unconsolidated bottom
E1UBL*	Estuarine Unconsolidated bottom
E2US*	Estuarine Unconsolidated shore
Remaining	

Though only 30 sites are to be assessed per watershed, 250 sample points are provided from the GRTS for overdraft. Historically it has been found that often the National Wetlands Inventory has errors, especially in the Delaware Estuary. Some parts of the Pennsylvania coverage were found to be as old as 1975. Since many wetlands have been loss since then, we needed to visit 59 points to find 30 that were still wetlands for a complimentary project. In addition, incorrect NWI data and/or land ownership and access permission issues sometimes necessitated point overdrafts for sites. Sites are assessed in the random order that the survey point drop yielded. If a site was determined to still exist as a tidal wetland habitat, then that site is assessed.

For each sample point, the center point was established from the GRTS design and a 50m radius assessment area (AA) was established around it. A 250m buffer area was also established using GIS around the AA. A team would go to the designated AA center and four 50-meter transects were run from that point at 90 degree angles from each other. The first transect was directed towards the main water way (tidal-influenced open water >30m wide), and the other three transects were extended from the center, clockwise from the first transect. Metrics were assessed at 25 and 50 meters from the center on each transect. Moving from the center along each transect, plant community and hydrology were observed. At the center point, water salinity, photographs and approximate organic soil depth were taken. After all transects were measured, direct observations and aerial photography were used to record conditions for site hydrology, buffer condition, and overall plant community condition.

Each site was given a specific name, as well as an integrated Qualitative Disturbance Rating (QDR) as judged by the survey crew after completion of the assessment in consideration of all factors for the entire site. A QDR rating is based on stressors and alterations to vegetation, soils, hydrology, and land use disturbance surrounding the site. A scale of least disturbed (score of 1) to highly disturbed (score of 6) is used. Generally a minimal disturbance, QDR of 1 or 2, is a natural structure and biotic community maintained with only minimal alterations. A moderately disturbance category, QDR of 3 or 4, is moderate changes in structure and/or the biotic community. A high disturbance category, QDR of 5 or 6, demonstrates sever changes in structure and/or the biotic community which could lead to a decline in the wetlands ability to effectively function in the landscape. The best scientific judgment method for assigning a QDR is further defined in the Mid-TRAM Version 3.0.

Results

Study Design Preparation

In early July, 2009 approximately 20 partners from the DEWMAP (later renamed MACWA) workgroup attended a workshop (Fig. 22) that was run by the Delaware's Department of Natural Resources and Environmental Control (DNREC). At the workshop DNREC employees explained the history of the Mid-Atlantic Rapid Assessment Method (RAM), which they are in the process of developing. The workshop ended with all of the participants going into the nearby marsh and being trained in the Mid-TRAM v.1 methodology.

Figure 22. DNREC staff presenting MidTRAM methods at a training workshop in 2009.

Methods Testing

During the spring of 2010, Partnership for the Delaware Estuary (PDE) staff were further trained on the latest rapid assessment protocols for Mid-TRAM v.2 by staff of DNREC. Some metrics had been dropped and a few had been modified since the group had last met. Methodologies and issues that could arise in the field were thoroughly discussed between the two teams.

Subsequently, PDE staff worked with DNREC to develop a new attribute and associated metrics to be tested as part of an updated Mid-TRAM. This new shoreline attribute initially included 5 candidate metrics to assess the degree of erosion and alterations along the seaward margin of tidal wetland sample points, factors that could be important for the wetland's resilience to effects of sea level rise and storms. After testing by both PDE and DNREC staff, 2 of these metrics were retained for inclusion in an updated Mid-TRAM v.3. Addition of this shoreline attribute is considered an optional component to the revised Mid-TRAM. The goal was to assess the condition of the seaward edge, balancing the assessment of the landward buffer (already in MidTRAM). The shoreline component scores can be omitted from the overall RAM scoring in cases where results are to be directly compared to other MidTRAM results which were already completed (i.e., scoring by MidTRAM v.2). If the shoreline component is included in the overall RAM scoring, the results will be presented as MidTRAM v.3 modified.

Since all of the methods for Mid-TRAM v.3 are detailed in the appendices, here we mainly describe methods for the new shoreline attribute that we developed. A shoreline was defined as the area between the edge of the vegetated marsh and mean low water along the nearest adjacent water body to the assessment area. The water body must be a tidally influenced creek or open waterway with a minimum width of 30 m. This criterion ensures that the water body has sufficient surface area and fetch to be exposed to wave and erosion energies. If no suitable water body is within 250 m of the center of the assessment area for a sample point, then shoreline condition was not be assessed for that point.

Figure 23. DNREC and PDE staff discuss shoreline metrics for RAM.

If >50% of the points do not meet these criteria and cannot be assessed for shoreline condition, and if additional funds allow for added fieldwork, then alternative points that satisfy these criteria are recommended to be selected and assessed to ensure that at least 15 points are assessed for the shoreline metric.

The following table summarizes the shoreline attribute metrics, representing a modification of the Metric Overview table on pg 12 of the MIDTRAM v. 2.0 pdf (Mid-TRAM v.3).

Table 13. Text and table from Mid-TRAM v3 of added shorline metrics and how they are measured (in brown).

SHORELINE (S)

Attribute	Metric	Description
SHORELINE	S1: Shoreline Alterations	Presence of built structures or non-natural materials along the shoreline at transect points, such as bulkheads, old wharfs, rip rap, but not natural materials such as shell, debris and living shorelines.
	S2: Shoreline Erosion	Shoreline condition at shoreline transect points based on the erosion:accretion ratio.

Article I. Attribute: 4: Shoreline

While shorelines naturally change and move, their susceptibility to increased wave action due to human activities, as well as sea level rise, are not fully understood in the Delaware Estuary region. In marshes, the shoreline represents the "front-line" for either retreating or advancing marsh.

Shoreline condition was assessed with two metrics; erosion and alterations (Table 14). Both of these metrics were assessed at the seaward termini for each of five transects that were oriented perpendicular to the shoreline as shown in Figure 24. These termini are referred to as "transect points."

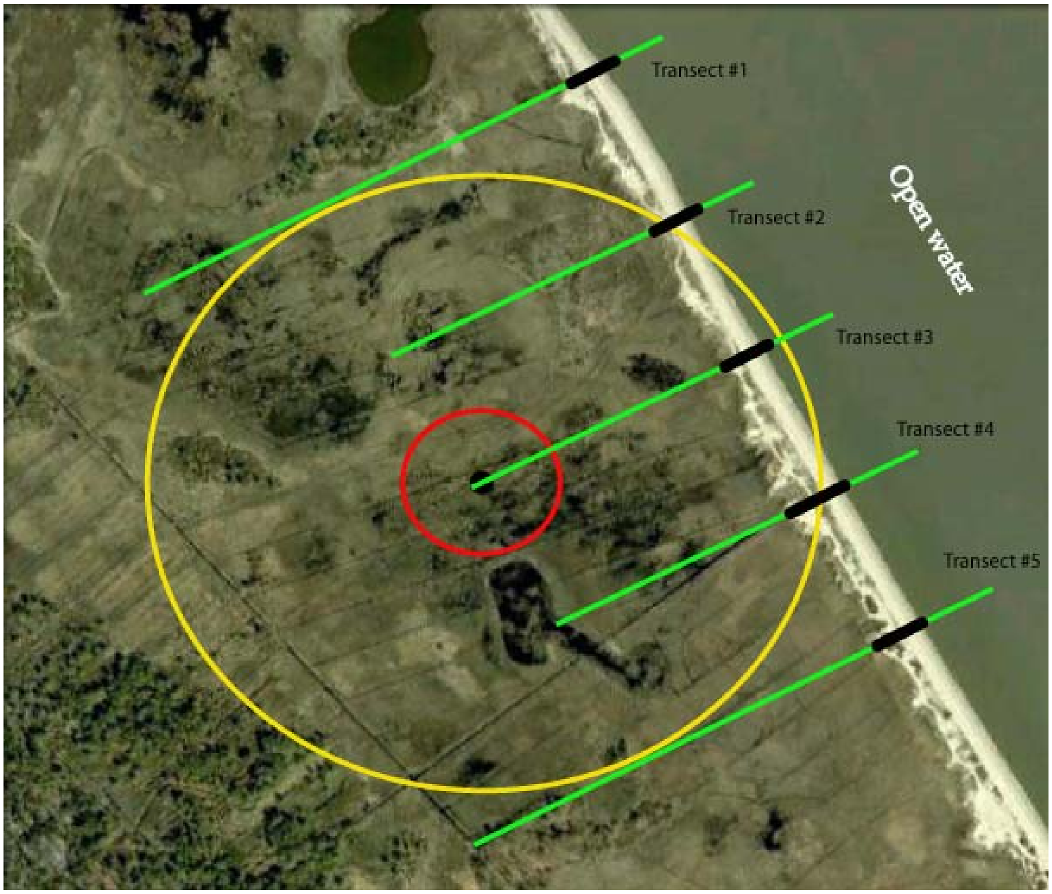

Figure 24: Configuration of the assessment area (red circle), buffer area (yellow circle), and shoreline transects (green lines) for each random wetland sample point.

Steps are outlined below for the shoreline assessment. Steps 1-3 for determining transect point location (as per Fig. 24) should be completed using GIS prior to field work and the target coordinates should be pre-loaded in a GPS unit prior to fieldwork. The field crew will survey shoreline condition at the five transect points using the predetermined GPS coordinates. Once in the field, the field crew can adjust the location (or delete as a last resort) transect points that are found to be inaccessible or unsuitable. If a point needs to be moved (in accordance with the MIDTRAM) then a transect will be drawn from the new point to the nearest tidal influenced, at least 30m wide, body of water. From this mid point (Point 3), the other 4 points can be determined by using GPS to pace out 150m in either direction from the midpoint then 300m from the midpoint in either direction. Shorelines are not assessed if they are human built or engineered, e.g., a levee or restored bay shoreline.

The shoreline assessment for a sample point begins by identifying the circular buffer area that extends 250m beyond the edge of the assessment area (AA.) Establish a linear transect from the center of the AA to the nearest tidal influenced body of water that is at least 30m wide. In cases where the shoreline is curved, the linear transect will still be set as the shortest distance between the center of the AA and the shoreline. In cases where the AA is situated within an impoundment and there is a man-made levee or some other hydrological impediment between the AA and the shoreline, the transect will be kept as long as the body of water is tidally influenced and at least 30m wide. If this is not true the next nearest tidally influenced, at least 30m wide, body of water will be used. In cases where transect is repositioned in the field, the location of the five transect points (see #1-5 below) will be set approximately 150m apart and actual GPS measurements will be recorded enabling calculation of exact distances later. A minimum of 3 transect points set at least 100 m apart are needed to constitute a valid shoreline assessment per point.

<u>Shoreline assessment steps:</u>

1. Find the nearest tidally influenced, at least 30m wide body of water.
2. Establish a transect from the center of the AA to this body of water. Where the transect intersects shoreline is Point #3.
3. Establish two transects that are parallel to the main center transect 300m on each side of the center of the AA, the outer boundary of the buffer area (see Figure 24).
4. Establish two parallel transects that are 150m from the center of the AA. Facing the water from the AA, the transects are consistently numbered from 1-5 moving from North to South or East to West. The five transects are 150m apart.
5. The intersection of Transects #1-5 with the shoreline are the Transect Points #1-5. See above for the definition of the shoreline.
6. Two shoreline condition metrics will each be assessed at each of the five transect points preferably during the time between mid-ebb and mid-flood tides if possible for consistency. Therefore, during field assessments, the shoreline assessment portion should be completed near the beginning or end of the effort per point to ensure that at least half of the intertidal zone can be surveyed for shoreline condition. If this time frame cannot be accomplished, and the shoreline cannot be adequately viewed, a score of “0”, stable, will be assigned.
7. At each point, for shoreline alteration the area of focus will be a 50 m wide band through the intertidal zone, extending from the seaward edge of the contiguous vegetation to the middle of the intertidal zone (since the low intertidal zone might not always be visible). Shorelines with steep slopes will have a smaller area of focus than shorelines with gradual or terraced slopes (e.g. for examples, see Figure 25). For the shoreline erosion metric, a 20m area of focus will be considered

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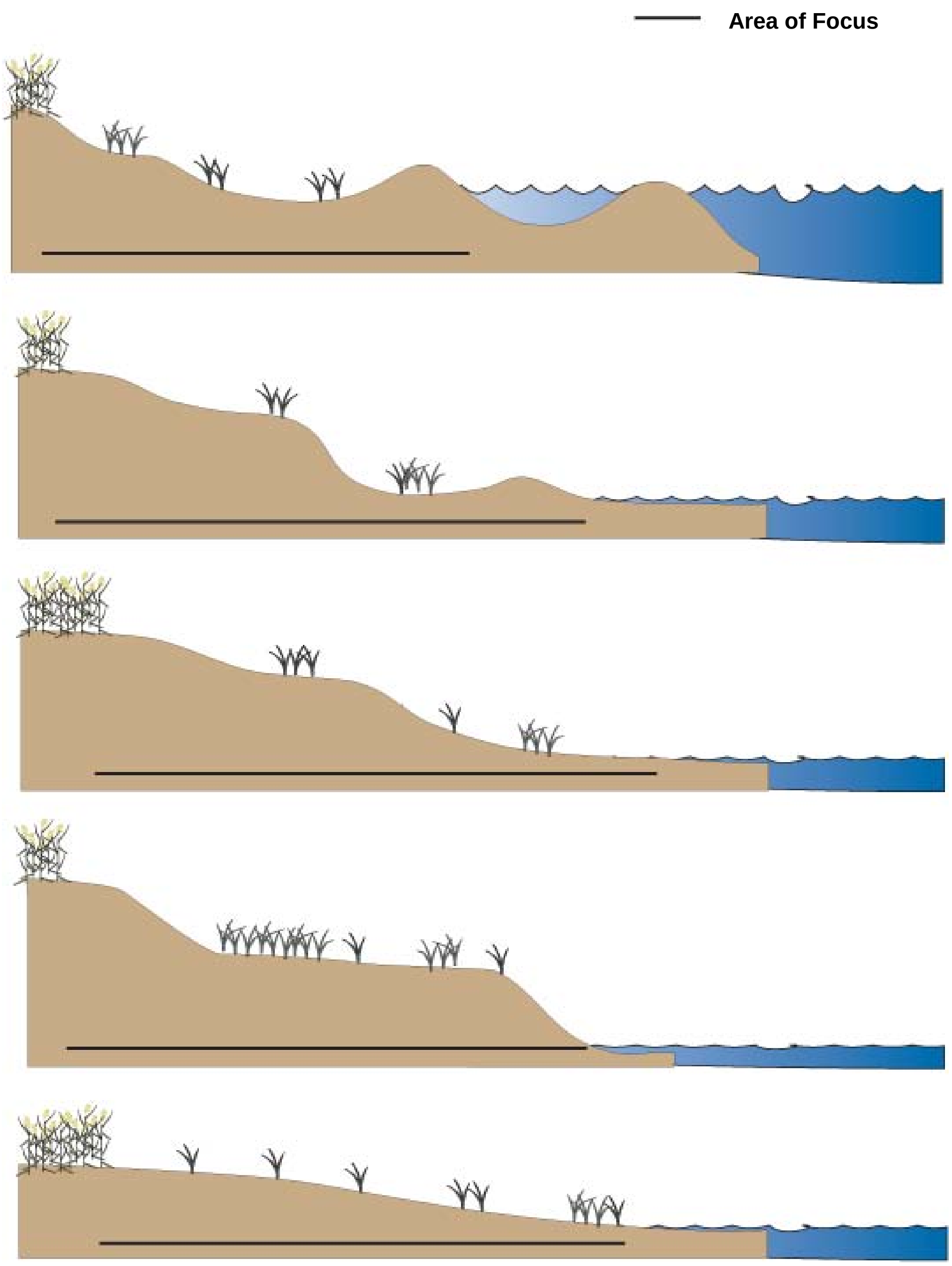

Figure 25. Area of focus (black line) for shoreline assessment for marsh edges having different slope configurations (shown at low tide). In all examples, the dense clump of taller grasses to the left signifies the seaward margin of the contiguous vegetation, whereas small clusters of grasses within the area of focus signify clumps of vegetation or broken terraces.

Article II. S1: Shoreline Alteration

Definition:
Shoreline alterations are built structures that consist of hard surfaces or substrates that are not typically found along tidal wetland shorelines. Any structure that shades or disrupts the normal hydrology; examples include bulkheads, rip rap, wharfs and piers. These structures and alterations can be derelict or still maintained (for examples, see Figures 26 and 27). Not to be included are restoration alterations that use soft or natural materials along the edge (e.g. some installed "living shorelines", Figure 28), flotsam, or natural fill such as shell piles or woody debris.

Assessment Protocol:
- Standing at the transect points scan the immediate viewable upper intertidal zone along the linear shoreline for 25 m in either direction. Assess whether this 50 m section of shoreline contains any shoreline alterations, and if so, measure the total linear shoreline that is altered (occupied by structures or otherwise manipulated.)
- At each transect point, measure the linear expanse of shoreline that is altered within the 50 m area of interest straddling the transect (25 m to either side.) Divide the altered shoreline length by 50 m to calculate a percentage of linear shoreline that is altered. Average this percentage among the (up to 5) transects.

Scoring: Shoreline Alterations

Percent Shoreline Altered	%
Site 1	
Site 2	
Site 3	
Site 4	
Site 5	
Average	

Article III. S2: Shoreline Erosion

Definition:
Standing at the transect point where the transect exits the contiguous vegetated marsh and begins to drop in elevation through the non-vegetated intertidal zone (i.e., between the contiguous vegetated marsh edge and the mid-intertidal zone on the foreshore,) scan the immediate viewable upper intertidal zone along the shoreline for 25 m in either direction. Assess whether this 50 m section of shoreline is eroding, stable, or accreting, on average. If this is unclear, score it as stable.

Assessment Protocol:

- Scan the shoreline for 10 m in either direction of the transect point, focusing on the intertidal zone between the contiguous vegetated marsh and the mid-intertidal zone of the foreshore. In this 20 m of upper intertidal shoreline, estimate if the average condition is either generally eroding (-1), generally stable (0), or generally accreting (+1).

  In cases where erosion or accretion is not evident, the area should be considered stable. If erosion and accretion are both evident, but balanced, then the shoreline is considered stable. Only score the area as eroding if >50% of the 20m is eroding, and only score it as accreting if >50% is accreting. If mixed patterns occur and it is unclear how to score the transect point, use a tape measure to dissect the 20 m into 10 m subsections (with the middle set on the transect point), score each subsection, average the scores, and round to the nearest whole number (-1, 0, 1).

  After all transect points are surveyed (minimum of 3, ideally 5), average the scores. These will range between -1 to +1.

Scoring:Shoreline Erosion

Approximate Shoreline Erosion	Generally eroding (-1)/ Generally stable (0)/ Generally accreting (+1).
Site 1	
Site 2	
Site 3- Mid Point	
Site 4	
Site 5	
Average	

Figures 26-36 picture some of the types of situations often encountered. Figures 26 and 27 show shoreline alterations that are non-natural and which would lower the score, whereas Figure 28 shows a marsh edge that was restored with a living shoreline and which would not be scored low because of the use of natural materials to stabilize erosion and upgrade ecological conditions.

Figure 26. Example of a shoreline alteration that is non-natural manipulation, a derelict pier.

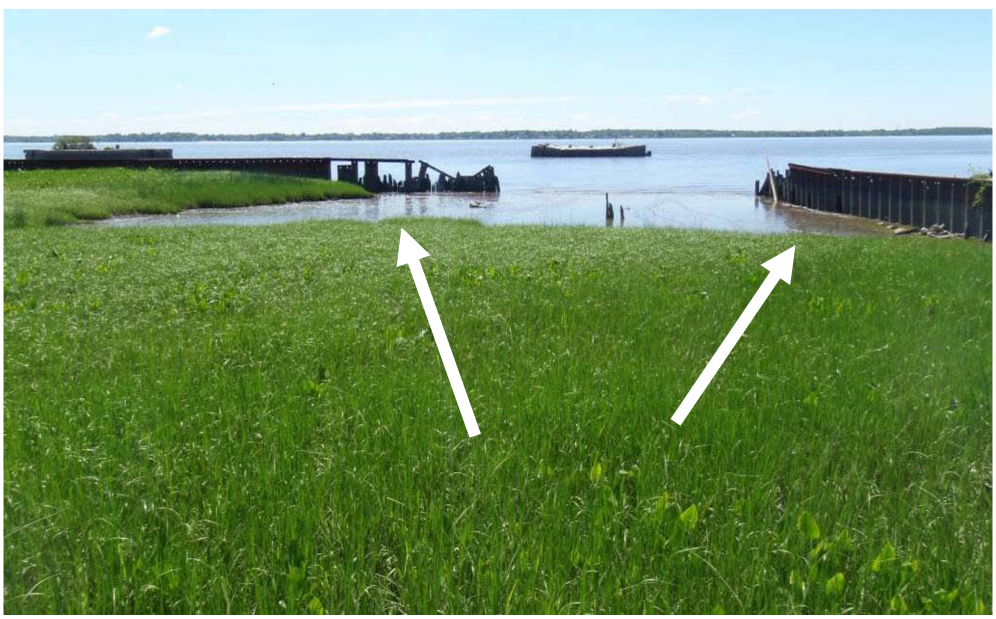

Figure 27. Example of a non-natural shoreline manipulation, bulkheads.

Figure 28. Example of living shoreline constructed of natural fiber logs and mats, oyster shell, and seeded with mussels and vascular plants.

See Figures 28 and 29 for examples of accretion and Figures 30-37 for various examples of erosion. Typically, accretion is evidenced by accumulated soft sediments and seaward colonization of the foreshore by sprigs of vegetation. Erosion is typically indicated by a lack of accumulated soft sediments, exposure of non-vegetated peat, peat terraces, and sharp slopes with undercut vegetation

Figure 29. Accretion and Erosion; marsh plants expanding from marsh edge towards water line, but clearly previous erosion behind with an undercut bank.

and cusps. This metric requires that the observer estimate whether the shorelines is either generally eroding, generally accreting, or is generally stable, within a 20 m shoreline section bounded 10 m to either side of the transect point.

Figure 30. Accretion; specifically of plants expanding onto foreshore.

Figure 31. Erosion; undercutting of banks leading to marsh slumping.

Figure 32. Example of erosion in the form of "cusping"


Figure 33. Erosion that exposes underlying peat.

Figure 34. Exposure of eroding peat and undercutting of banks.

Figure 35. Example of erosion in the form of terracing.

Figure 36. Example of erosion that is exposing plant roots and rhizomes.

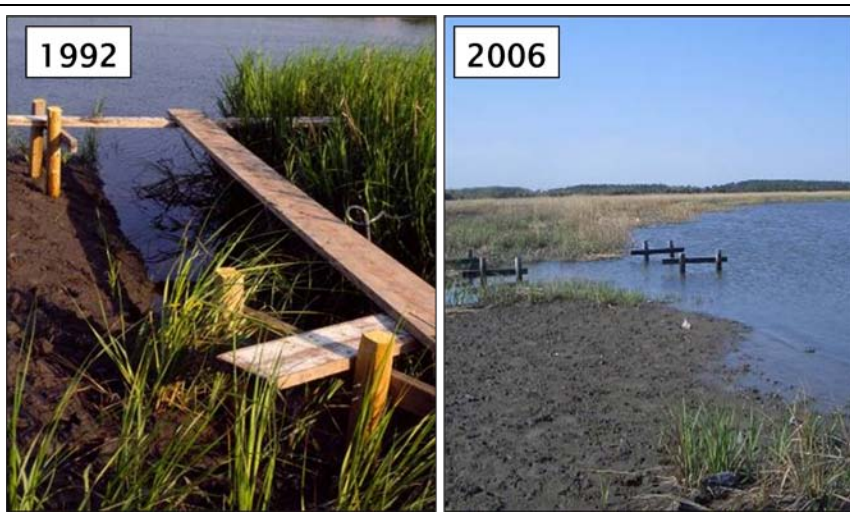

Figure 37**.** Evidence of water body expansion and landward marsh retreat can be found if structures are seen in the water that were formerly located within the marsh.

Quality Assurance

Following training, PDE staff participated in paired assessments with DNREC staff on July 20th, 2010. Quality assurance test are done in wetlands along the St. Jones river in Delaware. These were done to ensure that different field teams and organizations were applying the MidTRAM protocol consistently, and yielding the same results within an acceptable range. Three sites were assessed by both the DNREC staff and any PDE staff that would be performing the MidTRAM. Each site was assessed and results and technique were compared. DNREC found PDE's techniques meet their standards. The quality assurance tests yielded results that were not significantly different, and so the validity of PDE assessments compared to those collected by DNREC was confirmed.

RAM Testing

Following training and QA testing in 2010, PDE staff assisted DNREC in assessing some salt marsh wetland points in the Broadkill watershed of southern DE. Thereafter, PDE staff tested the suitability of the method in freshwater tidal wetlands of the upper estuary, including at Tinicum (PA) and along the Christina River (DE). Lists of appropriate flora and fauna species were developed for the different types of coastal wetlands encountered, including freshwater tidal wetlands of Pennsylvania. More rigorous testing of a new MidTRAM v.3 prototype was performed from late July through September in 2010. Version three of the MidTRAM was used to assess three sites (except at the Maurice) at each of the SSSIM sites; Christina, St. Jones, Maurice and Tinicum/Darby. PDE staff verified that the metrics in version 3 would indeed work at the tidal freshwater wetlands in both Delaware and Pennsylvania.

Ongoing RAM Studies

Following training, methods development, and testing of Mid-TRAM v.3, PDE staff used a subsequent wetland grant to begin assessing full watershed-wide sample point fields for the three studies watersheds (see SSIM section above). Resulting RAM scores for those watersheds will be reported separately for the other studies; but it should be mentioned here that the Mid-TRAM v.3 protocol continued to be found suitable for all types of coastal wetlands throughout the Delaware Estuary, as well as Barnegat Bay, NJ.

Site comparisons and summary

Although at least thirty sites are needed per watershed to make an overall assessment and it was not the goal of this project to perform a full watershed assessment, we can summarize data outcomes from the RAM R&D to preliminarily portray the type of information to be expected with full assessments. Tidal marshes along the St. Jones River in Delaware and the Maurice River in New Jersey were assessed for RAM tests in this study.

Tidal marshes of the Maurice had higher scores than those along the St. Jones River in Delaware, and this was true for all three attributes (buffer, hydrology, and habitat) in Mid-TRAM v.2. The overall score for Maurice marshes was 88 out of 100; whereas, marshes of the St. Jones scored a 72 out of 100 (Table

14). The Christina watershed in Delaware and the Tinicum watershed in Pennsylvania were both freshwater tidal and yielded similar, lower average scores (65 and 67, respectively). When comparing the data for specific attributes among these watersheds (e.g., Fig. 36), the buffer score was particularly low for the St. Jones and Christina watersheds, whereas Tinicum scored lowest for hydrology and habitat attributes.

Table 14. Example Mid-TRAM v.3 scores for tidal marshes in the vicinity of SSIM stations in four representative watersheds. Scores were based on 100 total possible points.

	Buffer Score	Hydrology Score	Habitat Score	**FINAL SCORE**
Maurice	86.7	100	76.7	**87.8**
St. Jones	51.1	88.9	75.6	**71.9**
Christina	48.9	75.0	71.1	**65.0**
Tinicum	66.7	69.4	64.4	**66.9**

Overall the saltwater marsh in New Jersey performed the best in all attributes and in the final scoring across all four sites (Fig. 38). In fact both salt marshes scored the highest amongst the four sites. This is not surprising considering the stresses placed upon freshwater wetlands including the cumulative effects of past and ongoing contamination, pollution, hydrologic alteration, and development in the urban corridor of the upper Delaware Estuary. Since many of these habitats have been diked, filled and otherwise altered, they are also more susceptible to invasive plants than in non-urban areas. Nevertheless, when taken together, all marshes studied appeared to be moderately or severely stressed on balance, and few were minimally stressed.

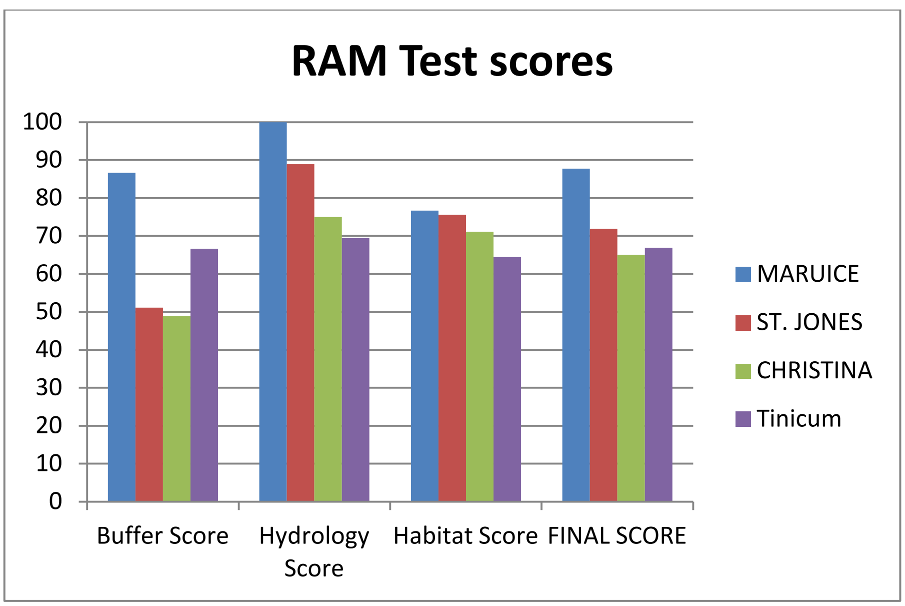

Figure 38. Average MidTRAM final scores and attribute-specific scores contrasted among tidal wetlands in four representative watersheds of the Delaware Estuary. Note that these data are preliminary, based only on RAM testing and not scientifically robust watershed assessments.

These results are very preliminary and do not represent scientifically valid surveys because of insufficient point densities; nevertheless, these results show how the overall scores and specific attribute scores can be contrasted among watershed regions to illustrate why and how some marshes might be more or less stressed by others (i.e. which factors are more problematic). These findings from rapid assessments have also been found to be useful in correlation studies that compare past and current land use practices to ascertain how wetland management practices (and mosquito control practices) contribute to wetland stress and reduced condition (Somers 2011).

Tables 15-18: MidTRAM v.2 data collected for 11 test sites that spanned sample points in four differing watersheds.

SITE #	CREW	DATE	TIME	WATERSHED	LAT/LONG	AA SHAPE	AA MOVED?	COMMENTS
NJ_MA_01	AP, WW, LW	9/16/2010	10:15-11:10	MARUICE	75°00'57.31"W 39°14'35.07"N	CIRCLE	NO	
NJ_MA_02	AP, WW, LW	9/16/2010	11:45-12:40	MARUICE	75°00'40.90"W 39°14'36.82"N	CIRCLE	NO	
DE_SJ_01	AP, WW	9/20/2010	1:00-3:00	ST. JONES	75°26'33.86"W 39°05'26.06"N	CIRCLE	NO	
DE_SJ_02	AP, WW	9/20/2010	11:10-12:15	ST. JONES	75°26'09.67"W 39°05'18.02"N	CIRCLE	NO	
DE_SJ_03	AP, WW	9/20/2010	3:15-4:25	ST. JONES	75°25'05.49"W 39°04'23.41"N	CIRCLE	NO	
DE_CH_01	AP, KS, WW, PC	9/17/2010	8:00-9:15	CHRISTINA	75°33'57.88"W 39°43'19.35"N	CIRCLE	NO	
DE_CH_02	AP, KS, WW, PC	9/17/2010	10:25-12:10	CHRISTINA	75°33'51.58"W 39°43'16.26"N	CIRCLE	NO	
DE_CH_03	AP, KS, WW,	7/30/2010	10:45	CHRISTINA	75°33'42.13"W 39°43'18.93"N	CIRCLE	NO	
PA10-TM-01	AP, KS, WW	8/19/2010	11:45-1:30	DARBY	75 15'47.37" W 39 53'02.04" N	CIRCLE	NO	
PA10-TM-02	AP, KS	8/13/2010	11:10-3:30	DARBY	75 15'47.13" W 39 52'57.23" N	CIRCLE	YES	> 10% open water
PA10-TM-03	AP, KS, WW	8/20/2010	10:00-11:30	DARBY	75 15' 55.58" W 39 52'55.42" N	CIRCLE	NO	

SITE #	CLASSIFICATION	TYPE	TIDAL STAGE	PHOTOS	STRESSOR PHOTOS	DISTANCE TO UPLAND (m)	DISTANCE TO OPEN WATER (m)	STABILITY
NJ_MA_01	Expansive Estuarine Tidal Fringe	Natural	2	388-391		967	32	healthy and stable
NJ_MA_02	Expansive Estuarine Tidal Fringe	Natural	1	392-395		575	119	healthy and stable
DE_SJ_01	Expansive Estuarine Tidal Fringe	?		415-418		90	919	healthy and stable
DE_SJ_02	Expansive Estuarine Tidal Fringe	?		411-414		125	935	healthy and stable
DE_SJ_03	Expansive Estuarine Tidal Fringe	?	2	419-422		112	104	healthy and stable
DE_CH_01	Fringing Estuarine Tidal Fringe	Natural	4	403-406		161	171	healthy and stable
DE_CH_02	Fringing Estuarine Tidal Fringe	Natural	4	407-410		226	157	healthy and stable
DE_CH_03	Expansive Estuarine Tidal Fringe	Re-establishment	3	154-157	walkway/boardwalk	73	91	beginning to deteriorate
PA10-TM-01	Expansive Estuarine Tidal Fringe	Enhancement	2	168-171	N/A	227	3	healthy and stable
PA10-TM-02	Fringing Estuarine Tidal Fringe	Assessment/Re-established/low marsh	2	164-167	168	323	0	beginning to deteriorate
PA10-TM-03	Expansive Estuarine Tidal Fringe	Enhancement	3	172-175		87	53	healthy and stable

SITE #	Salinity (ppt)	Organic layer (cm)	Comments	QDR
NJ_MA_01	25	26	fine silts with some clay/silt underneath	2
NJ_MA_02	17	>42	silty loam	2
DE_SJ_01	17	>40	lots of large rhizomes, silty organic, well hydrated	3
DE_SJ_02	22	11	well hydrated, fine silts on top, dark organic color	3
DE_SJ_03	23	>30	fine organics with large amount of roots	3
DE_CH_01	0.3	33	fine silt with clay	4
DE_CH_02	0.2	16	dark, fine organic layer with typha rhizomes and clay under	4
DE_CH_03	0	39.5	no clay or sand, very compacted	5
PA10-TM-01	0	25	minerally/clay	5
PA10-TM-02	0.2	37	organic root mat/ hydrated above and clay layer below	4
PA10-TM-03	0	2	debris on top of clay/ very clayey	4

SITE #	B1	B2	B3	B4	B5	Buffer SCORE	H1	H2	H3	H4	Hydrology SCORE	HAB1	HAB2	HAB3	HAB4	HAB5	Habitat SCORE	**FINAL SCORE**
NJ_MA_01	12	9	9	9	12	80	12	12	12	12	100	9	9	6	12	12	73.33	**84.44**
NJ_MA_02	12	12	12	9	12	93.33	12	12	12	12	100	9	9	9	12	12	80	**91.11**
DE_SJ_01	12	9	3	6	3	40	12	12	12	12	100	6	12	12	9	9	73.33	**71.11**
DE_SJ_02	12	12	6	6	3	53.33	12	12	12	12	100	9	6	9	12	12	73.33	**75.56**
DE_SJ_03	12	12	6	9	3	60	9	12	3	12	66.67	12	6	9	12	12	80	**68.89**
DE_CH_01	12	12	6	6	3	53.33	12	12	6	12	83.33	6	12	9	12	12	80	**72.22**
DE_CH_02	12	12	6	6	3	53.33	12	12	6	12	83.33	6	12	9	12	12	80	**72.22**
DE_CH_03	9	9	6	6	3	40	9	9	3	12	58.33	9	9	9	6	6	53.33	**50.56**
PA10-TM-01	12	6	12	6	12	73.33	12	3	3	12	50.00	9	9	9	6	6	53.33	**58.89**
PA10-TM-02	9	6	9	6	6	46.67	12	6	12	12	83.33	9	9	12	12	9	80.00	**70**
PA10-TM-03	12	9	12	6	12	80.00	12	12	3	12	75.00	9	9	9	6	9	60.00	**71.67**

Dissemination and Synergistic Outcomes

In addition to the grant-sponsored activities, this Wetland Program Development Grant made possible many other outcomes, including additional workshops and student training. A large number of scientific and technical presentations were give, with examples listed below.

Workshops. In addition to the field training that was held in July, 2009, for partners from the DEWMAP (later renamed MACWA) workgroup, a second larger workshop was held in Cumberland Community College on February 17th, 2010. One goal of the workshop was to share information on past, current, and planned tidal wetland monitoring from coastal New Jersey to coastal Delaware and Maryland. Another goal was to consider whether and how to develop a network, linking activities and sharing data for addressing sub-regional needs, such as climate planning. Fifteen participants provided talks for the workshop, followed by a discussion session at the end. More than 40 people attended from Maryland, Delaware, and New Jersey, and they represented diverse sectors including federal, state, non-profit, academia, etc. The workshop was received well and facilitated new connections among those in the region and beyond.

Training. In addition to the training and quality assurance checking between DNREC and PDE that was originally planned for this grant project, PDE staff also trained staff of New Jersey Department of Environmental Protection and the New York City Parks Department. These staff are believed to now be working on their own programs and state wetland strategies, which are expected to incorporate many of our RAM and SSIM methodologies, and which would provide data for the now more expansive MACWA effort. PDE staff and partner scientists at the Academy of Natural Sciences also joined a national SET methods technical workgroup to work towards consistent and rigorous methods for broad data consistency and standards.

Student Development. Several undergraduate and graduate students participated in this study as interns at PDE, interns at the Academy of Natural Science, and one M.S. student served as a PDE graduate fellow of PDE. The thesis research topic selected by this graduate student, Ms. Kelly Somers, would not have been possible without these synergistic research and development efforts at PDE, and her completed thesis represents an added value outcome for this project:

> *Somers, K. L. 2011. The contribution of land use stressors to current wetland condition in representative watersheds of the Delaware Estuary. Drexel University Department of Bioscience and Biotechnology. Master's thesis. 210 p.*

Example Presentations by PDE and Partners:

Society of Wetlands Scientists, 2012. Comparative analysis of coastal wetland health in the Delaware Estuary assessed using rapid methods. **Angela T. Padeletti,** Danielle Kreeger, Kelly Somers, Andrew Howard, Alison Rogerson¨ Poster.

Delaware Wetlands Conference, 2012. Mid-Atlantic Coastal Wetland Assessment: Monitoring wetlands through rapid and intensive methods. **Angela Padeletti**, Danielle Kreeger, Andrew Howard, Allison Rogerson, Tracy Quirk, and Martha Maxwell-Doyle. Poster.

Coastal and Estuarine Research Federation, 2011- Mid-Atlantic Coastal Wetland Assessment: Monitoring tidal wetlands through rapid and intensive methods to support better management strategies. **Angela Padeletti,** Danielle Kreeger, Martha Maxwell-Doyle, Amy Deller Jacobs, Tracy Quirk, David Velinsky, Thomas Belton, and Dorina Frizzera. Poster.

Delaware Estuary Science and Environmental Summit 2011-THE MID-ATLANTIC COASTAL WETLAND ASSESSMENT: INTEGRATED MONITORING OF TIDAL WETLANDS FOR WATER QUALITY AND HABITAT MANAGEMENT AND RESTORATION PLANNING. **Danielle Kreeger**, Martha Maxwell-Doyle, Amy Deller Jacobs, Angela Padeletti, Tracy Quirk, David Velinsky, Thomas Belton, and Dorina Frizzera. Talk.

INITIATION OF LONG-TERM MONITORING IN WETLANDS ALONG DELAWARE AND BARNEGAT BAYS. **Tracy Elsey-Quirk**, R. Thomas, D.J. Velinsky, Danielle Kreeger, Angela Padeletti, and Martha Maxwell-Doyle. Poster.

September 2011- Partnership for the Delaware Estuary Science and Technical Advisory Council and Executive Implementation Committee. Regional Management Strategy for Tidal Wetlands in the Delaware Estuary. **D. Kreeger** and A. Padeletti.

*Atlantic Estuarine Research Society 2010***-** Collaborative Assessment of Tidal Wetland Condition in Delaware, New Jersey and Pennsylvania. **Padeletti, A.T**., D. Kreeger, M. Maxwell-Doyle, A.D. Jacobs, T. Quirk, D. Velinsky, T. Belton, D. Frizzera and D. Bushek.

Conclusions

Rapid Assessment Method results show most places are degraded in condition and specific stressors were identified in specific watersheds. These RAM tools and results are now being used by state wetland scientists to draft and modify state wetland programs. For example PDE attempted to perform 30 RAM sites in the tidal portion of Pennsylvania. Fifty-nine sites had to be visited in order to achieve those 30 sites. Data from the National Wetlands Data for the region was as old as 1975, leading to sites falling on airport runways, sidewalks and other hard concreted surfaces. The issues that surfaced because of this lack of up to date data has lead managers to reexamine the sufficiency of the USFWS NWI layer as well as revisit wetland protection laws.

Next Steps

It takes several years of monitoring data to produce necessary trends in surface elevation (accretion, subsidence) for sea level rise planning. As such data accumulates, we expect station data to yield tools and decision support outcomes to strengthen state management of coast wetlands. In addition site-specific differences in water and sediment chemistry and biological integrity have been found to vary among watersheds stressed by different agents. Managers are beginning to use these findings and tools to address management needs.

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Appendices

Appendices are furnished as separate files because of their large file sizes. They are listed below along with website addresses where they can be downloaded.

Appendix A: MACWA QAPP
http://www.delawareestuary.org/science_stac_workgroups_wetlands_lit.asp

Appendix B: Mid-Atlantic Tidal Wetlands Rapid Assessment Method Version 3.0
http://www.delawareestuary.org/science_stac_workgroups_wetlands_products.asp

Appendix C: Somers, K. L. 2011. The contribution of land use stressors to current wetland condition in representative watersheds of the Delaware Estuary. Drexel University Department of Bioscience and Biotechnology. Master's thesis. 210 p.
http://www.delawareestuary.org/science_stac_workgroups_wetlands_lit.asp