PENNSYLVANIA COASTAL ZONE

MANAGEMENT PROGRAM

FINAL REPORT

Development of monitoring and Assessment Methods for Pennsylvania’s Tidal Freshwater Wetlands

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Monitoring and Assessing Pennsylvania’s Tidal wetlands of the Delaware Estuary

Partnership for the Delaware Estuary
2011

Partnership for the Delaware Estuary

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http://www.delawareestuary.org/science_stac_workgroups_wetlands_products.asp
Contents
Introduction .................................................................................................................................................. 9
A long history of abuse ................................................................................................................................ 12
Methods ....................................................................................................................................................... 14
Results ........................................................................................................................................................... 18
Summary ....................................................................................................................................................... 26
References ..................................................................................................................................................... 32
Appendix A: Mid-Atlantic Tidal Wetlands Rapid Assessment Method Version 3.0
Appendix B: Pennsylvania Tidal Wetland Report Card

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

Table of Figures and Tables
Figure 1. Tidal Wetlands of the Delaware Estuary (Reed et al. 2007). .............................................................. 9
Figure 2. 1777 map of wetlands in southern Philadelphia region. ................................................................. 12
Table 1. Attributes and Metrics of the PDE-modified version of Mid-TRAM v. 3.0................................. 17
Figure 4. Example of narrow wetlands bordered by uplands found outside Croydon, PA ....................... 18
Figure 5. Example of site that fell on a walkway in front of a house ............................................................ 19
Table 2. Acres of tidal wetlands assigned to different types in most recent NWI sample frame. Below;
distribution of sampling sites within sample frame. .................................................................................... 20
Figure 6. Example of site that fell an airport runway next to a airport terminal. ........................................ 20
Figures 7. The 30 sites sampled fell throughout Pennsylvania’s coastline .................................................. 21
Figures 8. Results of MidTRAM score. Green sites are minimally stressed, yellow are moderately stressed, red are severely stressed ............................................................ 22
Figure 9. Average attributes scores for all 30 PA sites .............................................................................. 23
Figure 10. Graph of three attributes with each metric within the attribute, with standard error bars... 25
Figure 11. Cumulative Distribution Function (CDF) graph showing wetland condition scores as a function of the wetland sample point “population.” Dotted lines represent breakpoints between condition
categories. Bottom: Pie chart showing percentage of sites that fall within minimally (27%), moderately
(37%) and severely stressed (37%). .............................................................................................................. 26
Figures 12. Trash smothering plant growth commonly found in PA tidal wetlands. .................................. 30
Figure 13. Displays mean columns and value, selected ranges, and standard deviation bars of the three
attributes and total score of Pennsylvania (PA), Broadkill, DE, and the entire 150 sites in Delaware
previously sampled. .................................................................................................................................. 31
Figure 14. Attribute 3, Buffer, metrics shown Pennsylvania (PA) scores vs Broadkill, Delaware and 150
sites throughout Delaware. ......................................................................................................................... 31
Figure 15. Example of low lying marsh with Nuphar lutea at John Heinz Wildlife Refuge at Tinicum, PA. ........................................................................................................................................ 33
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).

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), 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 suggests that these wetlands are increasingly becoming degraded and are 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.) 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 2011.

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). The strategy and DEWMAP followed 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 (focus of the present study),
- **Tier 3**: intensive studies to examine relationships among condition, function, and stressor impacts (some studies being performed by PDE partners),
- **Tier 4**: intensive monitoring of condition and function at fixed-stations monitoring at a smaller number of locations (being performed by PDE with partners)

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 below). Tier 2 assessments are critical to ground-truth and link Tier 1 census data to Tier 3 intensive 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, 2001)

Within the Delaware Estuary, the State of Delaware led has been the leader in developing RAM protocols (DNREC, 2010 and Jacobs, 2010), including both tidal and non-tidal wetlands. Two RAMS 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. Mr. Kevin Hess (PADEP), a member of the Delaware Estuary Wetland Workgroup, among others, has suggested that there are many differences between these tidal wetland types that need to be considered. 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, including freshwater tidal wetlands in Pennsylvania.
A long history of abuse

The original inhabitants of the region were the Lenape of the Algonquin group of Native Americans. The Lenape inhabited the area from Delaware to the lower Hudson River. It is known that the tribe cultivated the land in what is now known as Philadelphia. Europeans started to settle in the area in the early 17th century with Dutch, Swedish and English colonists arriving first. 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 south of the city was covered by tidal marshes (Fig 2), 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).

Also according to the Philadelphia Water Department, by the 1800’s The Neck had approximately six square miles of the neighborhood that were surrounded by wetlands that had both natural tidal creeks and man-made drainage canals. At the same time miles of dikes were built along both the Delaware and Schuylkill, allowing the inhabitants to use the land for growing crops 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.

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 but also the anthropogenic impact that is already taking place on the marsh.

“...It is celebrated for its cabbages, its pigs, its dogs, its dikes, its reed-birds, its inhabitants, and, above all, for its smells. 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 since that mythical coachman or horseman first rode along its marshy shore, when General Howe danced and Major Andre painted. 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.”

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 wetlands pre-European 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 nature in the area and yet it is 1 mile from a large international airport and bordered by Interstate 95.

The area around the refuge continues to be industrial. The Sun Oil Darby Creek Tank Farm is an oil tank storage facility located in the northern area of the Tinicum refuge. It was constructed on top of a rock quarry in the 1940s and into the 1950s. Groundwater from the Sun Oil Tank Farm property was shown to be contaminated with heavy metals as well as benzene. Additionally, a pipeline belonging to the Sun Oil Tank Farm leaked over 90,000 gallons of crude oil into the refuge impoundment in late 1999 and early 2000. Just to the south of the tank farm was the Delaware County Sewage Treatment Plant which was operational from the late 1950s through early 1970s. The Sewage Treatment Plant discharged treated water into Darby Creek until its shutdown in the 1970s. Sludge from the plant was moved to a sludge disposal area but was never removed. Other impacts to the wetland include the Clearview Landfill which was operational from the 1950s until it shut down in 1973. It was used as a landfill for municipal and industrial waste mainly from Philadelphia (NOAA, 2003).

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 in pockets 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 et al. 2011). 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, in prep). 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. What is not known is whether these losses have occurred because of direct conversion or declining health. This project sought to characterize the health of the remaining
tidal wetlands as a necessary first step in determining causes of decline and potential remediation methods in the future.

**Methods**

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 protocol was developed using data collected in the Indian River watershed (DE), Naticoke watershed (MD) and York watershed (VA) in 2006 and 2007. Numerous metrics were used on these watersheds, 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 based lessons learned from accumulating experiences and data. Some metrics have been added and some removed.

The current design of the Mid-TRAM, which was partially adapted by PDE, captures three attributes important to tidal wetlands; plant community, hydrology and buffer (Table 1). 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 score of 0-100 scale. The attributes are then averaged to provide a composite Mid-TRAM score.
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 = ((Buffer + Hydrology + Habitat)/3)

The latest version of Mid-TRAM can be accessed online at; http://www.dnrec.delaware.gov/wr/INFORMATION/OTHERINFO/Pages/WetlandMonitoringandAssessment.aspx. It takes approximately two to three people, one to two hours to perform the MID-TRAM. In tidal wetlands, the stage of tide 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 within a watershed for a representative assessment of that watershed’s wetland health. Sites are determined using a probabilistic method. The array of points is 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 was used. The GRTS design includes reverse hierarchical ordering of the selected sites. This layer was developed from the National Wetlands Inventory Maps that were clipped to the tidal Pennsylvania watersheds. This layer can be found on the National Wetlands Inventory website at: http://www.fws.gov/wetlands/Data/DataDownload.html.

The targeted population was vegetated tidal wetlands so some original coverage’s had to be removed from the original layer. The following was deleted:

<table>
<thead>
<tr>
<th>Class equal to</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>L*</td>
<td>Lakes and millponds</td>
</tr>
<tr>
<td>R1UBL</td>
<td>Riverine Unconsolidated bottom</td>
</tr>
<tr>
<td>E1UBL*</td>
<td>Estuarine Unconsolidated bottom</td>
</tr>
<tr>
<td>E2US*</td>
<td>Estuarine Unconsolidated shore</td>
</tr>
</tbody>
</table>

Though only 30 sites were to be assessed, 250 sites were provided from the GRTS due to the fact that the National Wetlands Inventory in this area was done in 1975, and it was known that further development of the region had gone on since then (see results section for the number of NWI wetland points that needed to be examined to find 30 points within extant wetlands.)

In depth methods can be found for the Mid-TRAM at http://www.dnrec.delaware.gov/wr/INFORMATION/OTHERINFO/Pages/WetlandMonitoringandAssessment.aspx. In summary; sites were assessed in the random order that the survey design yielded. If a site was determined to still exist as a tidal wetland habitat, then that site was 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 severe 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.
Table 1. Attributes and Metrics of the PDE-modified version of Mid-TRAM v. 3.0.

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

**Study Design Preparations.** The Partnership for the Delaware Estuary under its Science and Technical Advising Committee formed the Mid-Atlantic Coastal Wetlands Assessment (MACWA) workgroup. This group consists of staff from the states of Pennsylvania, New Jersey and Delaware as well as local academics such as Rutgers University, Drexel University and the Academy of Natural Sciences. In 2009, this group met approximately once a month throughout a six-month period to discuss sampling strategies and methodologies of both rapid and intensive monitoring. In early July 2009 the workgroup participated in a workshop about MidTRAM that was coordinated by DNREC. At the workshop, DNREC employees explained the MidTRAM protocol and performed a field demonstration. Later that month, PDE undertook two reconnaissance trips to Tincum Marsh on Darby Creek in Pennsylvania to determine access points and possible sampling positions for the following year. On August 13\(^{th}\), the Partnership and Pennsylvania’s Department of Environmental Protection staff embarked on a boat excursion up the Delaware River from Philadelphia to Trenton. Among other things, the staffers located marshes along the river and preliminarily examined their condition.

**Methods Testing and Quality Assurance.** During the spring of 2010, Partnership for the Delaware Estuary (PDE) staff were fully trained on the latest rapid assessment protocols being developed by staff of DNREC. A few 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 metric to be tested as part of an updated Mid-TRAM. This new “shoreline” metric was developed to address erosion and alterations along the seaward margin of tidal wetlands, factors that could be important for the wetland’s resilience to effects of sea level rise and storms. Data for this new shoreline component was collected by PDE and DNREC in all subsequent assessments, and the results will be examined to determine whether the overall Mid-TRAM protocol should again be updated to include this new component (in progress).

Following training, PDE staff participated in paired assessments with DNREC staff as a quality assurance test to ensure that different field teams and organizations were applying the MidTRAM protocol consistently, and yielding the same results within an acceptable range. The quality assurance tests yielded results that were not significantly

![Figure 4. Example of narrow wetlands bordered by uplands found outside Croydon, PA](image)
different, and so the validity of PDE assessments compared to those collected by DNREC was confirmed.

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.

Use of the MidTRAM in PA. The MidTRAM can only be performed during “peak” growing season, which in this areas occurs between early July and the middle of September. Between August 25th and September 16th 2010, PDE staff assessed 30 tidal wetland sites in the Pennsylvania portion of the tidal Delaware Estuary. Our focus was on tidal wetlands dominated by emergent vascular plants. We did include sites that were mud flats, shrub/scrub, forest, or benthic algae dominated even though NWI does include some of these habitats as wetlands. Our focus on emergent marshes dominated by vascular plants was justified because this is the wetland type that is most predominant in the landscape and most important ecologically.

To achieve 30 wetland sites that met our criteria, the actual number of points needed from the EPA point overdraft was 59. Therefore, approximately half of the sites that were predicted to be tidal wetlands based on most recent NWI data (1970’s-1980’s generally) were in fact no longer tidal wetlands. This was a much greater proportion that we have encountered to date in any other sub-watershed areas of the Delaware Estuary, presumably due to the conversion or deterioration of a significant amount of tidal wetlands.

Many of these non-wetland sites consisted of uplands, parking lots, driveways, airports, etc (Fig 5 & 6). There were no points in open water. This finding suggests that the lost wetlands did not drown or erode away as a result of sea level rise or some other factor. Rather, the high number of lost sites appeared to be directly attributed to filling or conversion because they became non-tidal and apparently higher in elevation. Since some of the NWI data were up to 36 years old and the study region is highly urban, we presume that the wetland losses resulted most likely from intentional filling and development.

The 30 assessed points occurred in a variety of different tidal wetland types, ranging from low marsh habitats dominated by succulents to high marsh areas dominated by cattails, wild rice, and various other tall grasses, sedges and rushes (Fig 7). We did not encounter any forested
tidal wetlands in this survey. Due to the limited and highly patchy nature of tidal marshes within PA (compared to historic marsh coverage,) many of the 30 points were near to each other; however, no points had overlapping buffer areas (600 m diameter circles). Hence, the QA requirements and criteria in the MidTRAM methodology were met. Only 1 point had to have the circular assessment area altered to a rectangular assessment area, and this realignment followed the standard protocol which is part of the MidTRAM.

The initial sampling frame used to drop the random points consisted of 464.9 acres of tidal wetlands within the Pennsylvania watersheds that border the Delaware Estuary, as determined by NWI. As noted above, considerable wetland loss clearly has occurred since the most recent NWI, and we surmise that less than 350 acres remain overall. Only a subset of this is emergent marshes dominated by vascular plants because the Cowardin classifications included in the full NWI sample frame are freshwater emergent wetlands, freshwater forested/shrub wetlands, riverine tidal wetlands, and others such as mud flats and algae beds. Table 2 shows the expected acreage of major wetland classification types as indicated by most recent NWI and which were used in our GRTS design. According to the most recent NWI data only 41 acres of the 400+ were designated as freshwater emergent wetlands, which was this study’s focus. It is unclear whether the forested and shrub/scrub wetlands listed in NWI are in fact still tidal as well.

<table>
<thead>
<tr>
<th>Sample Frame Summary</th>
<th>PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal Wetland area (acres)</td>
<td>464.90</td>
</tr>
<tr>
<td>Freshwater Emergent Wetland</td>
<td>41.40</td>
</tr>
<tr>
<td>Freshwater Forested/Shrub Wetland</td>
<td>251.97</td>
</tr>
<tr>
<td>Other</td>
<td>4.91</td>
</tr>
<tr>
<td>Riverine</td>
<td>166.10</td>
</tr>
<tr>
<td>Total</td>
<td>464.90</td>
</tr>
</tbody>
</table>

In total, 47% of the randomly dropped points needed to have the AAs moved to satisfy the MidTRAM protocol. This is not uncommon because often the random point drop places the center of the AA along the edge of a tidal creek or upland, and it needs to be shifted slightly to ensure sufficient wetland gets assessed. Indeed, the most common reason for moving the AA
was that the site included >10% open water. A lesser number of sites needed to have the center moved because the site had >10% upland. All sites were moved less than 100m from the original position.

Typically, rapid assessment protocols are best applied when the site is accessible and able to be walked; i.e., when the tide is not covering the wetland. The average tidal stage during all assessments was 2.5, just below middle stage. All sites were expansive or fringing tidal wetlands, and there were no “back barrier estuarine tidal fringe” (a wetland category in Mid-TRAM). The average distance to upland from the center of the AA for all sites was 99 meters. The average distance to open water was 73m. The salinity was 0 ppt for all sites. The average depth of the organic layer was 21 cm. The average percent of assessment area perimeter with a 5m buffer was 98%.

The average width of the buffer surrounding the AAs was 133m, but with wide variability ranging from 23-250m. The average percent of the area between the AA and buffer that was comprised of development was 8%, ranging between 0-50%. Suburban, urban, and industrial development such as lawns, yards and golf courses that are mowed and maintained open were considered developed. Agricultural land was not considered developed, but that was not present in any AA buffer (Fig 11).

Importantly, an average of 41% of the buffer surrounding each AA was obstructed to potential landward migration. The average distance from the center of the AA to the closest barrier to landward migration was 146m, ranging from 1-300m. These data suggest that the freshwater tidal wetlands in Pennsylvania are significantly constrained by development along their landward margins.
The average shoreline erosion was 0, and the average shoreline alteration was also 0. These data suggest that the freshwater tidal wetlands in Pennsylvania are not experiencing substantial erosion or degradation along their seaward margins.

Hydrologically all sites scored high in all metrics, Figure 11. There is little to no evidence of historic ditching and draining of the marsh left in the urban corridor. The second metric does not count historic fill so scores were not degraded because of that, though some sites scored lower because of the fragmentation of small parcels of wetlands. The lowest scoring metric within the hydrology attribute was metric #3, diking and tidal restriction. There was no evidence of diking left in the area but tidal restrictions due to raised walk ways and roads did cause sites to be scored lower. Also while it should be evident that there would be point sources near to an urban area, the current definition the protocol uses does not capture urban inputs, current modifications are currently under discussion.

The biological community was characterized by average diversity of vascular plants, with low invasive cover. The average number of plant layers was 3. Invasive plant species averaged 7% of the percent cover within the AA’s, ranging from 0-45%. Within the habitat attribute metric #1, bearing capacity, scored the lowest overall, Figure 11. This could be due to the nature of Tinicum marsh, where most sites were situated. Tinicum marsh is typically very soupy in nature. It is not assumed that a low bearing capacity in this instance points to sudden marsh dieback or interior decay. This state most likely is a stable state for the marsh. The metric that implies above ground biomass scored the second worse in this attribute. It is unknown why this metric scored low. Further data will have to be collected to make
a more conclusive answer. Metric 3, number of plant layers, indicate there is a good amount of plant diversity within the marshes, and metric 4 and 5, percent co-dominant invasive species and percent invasive cover respectively, show a relatively healthy marsh system for plant communities.

Following detailed site assessments for buffer, hydrology and biotic conditions, an overall grade is assigned to each point using best scientific judgment of the field crew. This grade is referred to as the Qualitative Disturbance Rating (QDR), with low values (1,2) reflecting generally good condition and high values (5, 6) reflecting generally poor condition. The average QDR for all 30 assessed points was 3.9 out of 6 (moderately stressed). The average Buffer/landscape score was 59 out of 100. The average Hydrology score was 90 out of 100. The average habitat score was 70 out of 100 (Fig. 9). The average overall score was 74.

Methodology referenced in Rogerson et al. 2009 was used to calculate the breakpoints to place all sites into three condition categories; unstressed to minimally stressed, moderately stressed, or severely stressed. A 25\textsuperscript{th} percentile of MidTRAM overall scores for sites with QDRs of 1 or 2 was used to separate out unstressed and minimally stressed. A 75\textsuperscript{th} percentile of MidTRAM scores of sites with QDRs of 5 or 6 was similarly used to separate severely stressed sites.

Minimally stressed or unstressed sites had composite scores higher than 81.1, and only 8 of the 30 sites achieved this standard. A total of 11 sites were characterized as moderately stressed, having MidTRAM composite scores between 67.8 and 81.1. Severely stressed sites had scores below 67.8, and this included 11 sites. A map of the sites and their category of stress can be seen in Figure 8. A cumulative distribution function (CDF) was calculated to display the population level results (Fig 11). By overlaying the breakpoint results (see MidTRAM protocol), we estimate that half of the wetlands in the region would score above a 75 and the other half less than a 75.
Table 2. Stressor prevalence in PA tidal wetlands

<table>
<thead>
<tr>
<th>Metric Averages</th>
<th>Minimal n=8</th>
<th>Moderate n=11</th>
<th>Severe n=11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to upland</td>
<td>171</td>
<td>102</td>
<td>45</td>
</tr>
<tr>
<td>% cover by invasive plants in AA</td>
<td>2</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>% perimeter obstructed by migration</td>
<td>0</td>
<td>33</td>
<td>77</td>
</tr>
<tr>
<td>% development in buffer</td>
<td>0</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>Buffer width</td>
<td>179</td>
<td>117</td>
<td>116</td>
</tr>
</tbody>
</table>

The overall average score for all 30 sites was 73.78, which we simplified into a letter grade of “C” for characterization of our results for the public. It is important to note, however, that this generally reflects the mean of the distribution of conditions encountered in this study, ranging from bad to good relative to each other. To our knowledge, this was the first RAM study of tidal freshwater wetlands in the Delaware Estuary, certainly the first in the heavily urbanized estuary. Future RAM assessments across the Delaware Estuary, and in other mid-Atlantic estuaries, will help to place these PA RAM data into a broader context, perhaps necessitating reinterpretation as new reference and impairment sites are encountered and assessed (we are now training staff from New York City to use the MidTRAM similarly in tidal wetlands). In 2011 PDE will used the same method to assess the Christina watershed in northern DE, another heavily impacted urban estuary with low salinity. As soon as those data are analyzed (and other watersheds we assessed in 2011), we will be better positioned to examine the PA RAM outcomes in the broader context of the Delaware Estuary.
In 2011 PDE prepared a public outreach brochure to explain the results of this study. This will serve as a “report card” on Pennsylvania’s remaining coastal wetlands. Included will also be information about why these wetlands are rare and important, why and how they are monitored, and concerns about their future. (Appendix B). This piece was developed using a successful model created by DNREC, which has been well received by the public. PDE will distribute the report card at its various outreach activities, such as Pennsylvania Coast Day, as well as providing copies for distribution at the Heinz Tinicum Wildlife Refuge. By informing the public about the status of these endangered wetland habitats, they will be more supportive of policies to protect what is left.

**Figure 10.** Graph of three attributes with each metric within the attribute, with standard error
Summary

Freshwater tidal, brackish and salt marshes are a hallmark feature of the Delaware Estuary where they represent perhaps the most critically important habitat type for both ecosystem and human health. In addition, freshwater tidal wetlands that characterize the upper Delaware Estuary are nationally rare and have long been impacted heavily by their location within the urban corridor.
Nowhere are freshwater tidal marshes more threatened than in Pennsylvania. PDE estimates that less than 5% of pre-settlement acreage remains in Pennsylvania (a few hundred acres at most). These wetlands were lost because of direct man-made disturbance and conversion, exacerbated by pollution, dumping and floatable debris. Although wetland filling certainly began hundreds of years ago, even today the losses continue to mount despite clear national policies (no net loss) to protect these vital habitats. We used the most recent USFWS wetland maps (National Wetland Inventory data from the 1970’s-1980’s) to prepare for our survey, but unfortunately we needed to visit 59 points to find 30 that were still wetlands. Although it was not our goal to examine acreage changes in this study and so the data are inconclusive, we can infer that a sizeable percentage, perhaps half, of the tidal wetlands that were present 30-40 years ago were lost in Pennsylvania since that time.

These losses did not appear to occur because of natural causes since none of the former wetland sites had converted to open water, and our shoreline condition assessment found that none of the 30 assessed sites were experiencing any significant shoreline erosion or alteration. Rather, the losses appeared to occur because of either natural encroachment of upland forests into wetlands or (more likely) direct filling and development. Sites that were classified as tidal wetland habitats consisted of paved roads, airport run-ways, houses, large manufacturing warehouses, and some shoreline that had obviously been filled.

Large expansive marshes once existed to the south of Center City Philadelphia, and to the north and south of the confluence of the Schuylkill and Delaware Rivers. This area, once called “the neck,” was a mud and wetland rich landscape with tremendous plant and bird life. With Europeans settlers came change and hundreds of years of wetland filling, ditching, and diking, plus all manner of toxic runoff. Thousands of acres of coastal wetlands became reduced to 495 acres by 1975 (most up-to-date data), and presently, we estimate that perhaps 200-300 acres remain.

The lack of current acreage data for coastal wetlands significantly hampered our efforts to perform this study. Although NOAA’s land cover datasets are valuable for tracking total wetland acreage, they lack the resolution and rigor to discern between tidal and non-tidal wetlands. All wetlands are ecologically vital and supply diverse ecosystem services for people, but tidal wetlands are unrivaled in this regard and have the added importance of protecting coastal communities against sea level rise and storm surge, both of which are predicted to become more problematic in the future. Regular updating of National Wetland Inventory (NWI) datasets is critical for coastal managers and scientists to monitor changing conditions and to enforce state and federal laws. As part of our updated estuary-wide wetland strategy, PDE has elevated the need for NWI updates in Pennsylvania as a top priority estuary-wide (recent updates to NWI are available for Delaware and New Jersey).
Fortunately, most of the remaining acreage of freshwater tidal wetland in Pennsylvania exists within the protective borders of the Heinz Tinicum National Wildlife Refuge operated by the United States Fish and Wildlife Service. This will help to prevent creeping development that appears to still be affecting coastal wetlands elsewhere in the state. However, even the wetlands within the refuge are threatened by the expansion of the regional airport, hydrological and water quality impairments from adjacent highways, upstream development that contributes to flooding and floatable debris, etc.

Beyond the Heinz Tinicum refuge, coastal wetlands exist in a patchwork of very small parcels. These are most often comprised of low marsh fringing borders of tidal creeks and the larger tidal rivers. Most are smaller than an acre. Some of the largest tracts north of the city of Philadelphia are restoration wetlands, which were reconstructed or created with funding from mitigation projects (highways, landfills, excavations). These wetlands were assessed as part of this study, and we observed that many of these had severely compacted soils and other unusual characteristics. Although most restored wetlands are not comparable to natural wetlands in condition, function and biotic diversity, these restoration sites clearly form an important and growing component of the remaining acreage and must also be carefully protected.

Our rapid assessment results indicate that the bulk of Pennsylvania’s tidal wetlands are severely or moderately stressed. This is important because most of the significant functions provided by coastal wetlands, such as primary production, secondary production, carbon and nutrient sequestration, denitrification, contaminant removal, fish and wildlife support, and coastal flood protection, are reduced or compromised when the condition of the wetland is degraded by stress. Therefore, efforts to restore coastal wetlands can go beyond simple acreage expansion projects. Projects that enhance the health and well-being of wetlands might boost ecosystem services per acre and impart more resilience and longevity. Condition enhancement projects can take many forms, such as by removing stressors, removing hydrological impairments, controlling invasive species, supplying sediment, removing trash, and building protective living shorelines.

Many metrics were assessed to calculate condition scores, and these were categorized as buffer integrity, hydrological integrity, and biological integrity. In comparison to our experiences in other states and wetland types in the Delaware Estuary, the most important overall type of impairment for Pennsylvania’s tidal wetlands was the lack of a quality buffer habitat. Most tidal wetlands in Pennsylvania were directly bordered by urban development or large highways such as Interstate 95. Since virtually all assessed sample points abutted intractable barriers to
landward migration, this is likely to pose an increasing challenge in the coming decades due to the predicted increase in sea level, storm intensity, storm frequency, and freshwater runoff/flooding. The increased volume of the Delaware Estuary is also expected to boost tidal currents and tidal range, which could lead to more erosion. The expanded surface area of open water and associated fetch for wind could also generate larger waves. To some degree, these expected changes could be partially offset by increased sediment supply from flooding, perhaps aiding them in their vertical accretion and ability to keep pace with rising sea level. Our shoreline condition metrics did not reveal any significant problems with erosion at this time (unlike salt marshes lower in Delaware Bay).

Considering the barriers to landward migration, the future of freshwater tidal wetlands in Pennsylvania will largely hinge on their ability to vertically accrete in place, and there are many actions that can be taken to ensure that they do so (e.g., living shorelines, beneficial use of dredge spoil) when and where needed.

Despite the obvious impairments to Pennsylvania’s tidal wetlands, the overall composite condition scores were generally comparable to other sub-watersheds that have been assessed lower in the Delaware Estuary. Figure 13 shows the scores of the three attributes of the 30 Pennsylvania sites (PA) compared with 31 sites in lower Delaware in the Broadkill watershed. Also shown in this figure are average scores for the same attributes for a larger dataset of 150 sites sampled across Delaware. The impact of the urban “squeeze” on Pennsylvania’s tidal wetlands is apparent in this comparison whereby the buffer attribute scored lower in Pennsylvania than for tidal wetlands assessed elsewhere where development is not as complete as in the urban area around Philadelphia. Interestingly however, the overall scores were not dissimilar because Pennsylvania’s tidal wetlands scored higher for biological and hydrological condition than the Delaware wetlands, which are impaired by a range of stressors such as mosquito ditching and low diversity.

In this report we have mainly presented the summary data for the three attributes along with the overall condition scores. However, Appendix A contains data for the diverse metrics that yielded the overall scores, and an analysis of these data can help to describe the specific stressors and conditions as specific locations. This information can also be useful for answering particular questions. For example, the depth of the peat layer and bearing capacity measures can be consulted to gauge the structural integrity of the marsh platform, and the taxonomic datasets can be used to examine diversity or construct field keys. With regard to the buffer attribute, Figure 14 summarizes, compared to 30 sites within Broadkill, DE and 150 other PA sites, data for Metric B3, percent surrounding development in the buffer is higher. Surrounding development includes suburban, urban and industrial development as well as lawns, yards and golf courses. Metric B5, barriers to landward migration, varied considerably,
but was slightly lower between the Pennsylvania sites and the other Delaware sites. Fourteen sites were within the interior of the Heinz refuge and had no significant barriers to landward migration (average percent perimeter obstructed to migration was 36%), whereas sites outside the refuge had much more significant barriers (average percent perimeter obstructed to migration was 65%). 

Along with pressures of encroaching development, wetlands in an urban area have other unique issues. A surprising amount of trash was found completing covering many areas of wetlands. Large tracts were partially coated with floatable debris that varied from plastic bottles to very large items such as garbage cans, televisions, shopping carts, portable toilets, and a full shower stall. In many places the shear amount of trash was clearly smothering plant growth. Many areas resembled an active landfill, especially along the margins of Darby Creek which is prone to flooding. The John Heinz National Wildlife Refuge at Tinicum performs a wetlands trash clean-up once during each spring. A more frequent and thorough cleaning of these marshes would need to be done to keep the marsh healthy. It is possible that the amount of trash is not only smothering plant production and directly curtailing ecological function, but the unvegetated mud created by the trash could facilitate colonization or expansion of invasive species. Large areas of Pennsylvania’s remaining tidal wetlands are already covered in the invasive reed, *Phragmites australis*. More research is needed to examine the effects of floatable debris on wetland health and function.

In the urban corridor where development pressure is high, it is vitally important to closely monitor the remaining tidal wetlands. The high level of stress and continuing loss of acreage suggests that many of these marshes are compromised or directly impaired on an ongoing basis despite the net gain strategy of the State of Pennsylvania, which includes protection, restoration and creation of wetlands, and acknowledges the importance of these wetlands as critical in achieving Pennsylvania’s water quality standards and goals. These findings suggest that this strategy could be further strengthened by including monitoring and enhancement projects that seek to sustain healthier condition of the remaining tidal wetlands within Pennsylvania.
Figure 13. Displays mean columns and value, selected ranges, and standard deviation bars of the three attributes and total score of Pennsylvania (PA), Broadkill, DE, and the entire 150 sites in Delaware previously sampled.

Figure 14. Attribute 3, Buffer, metrics shown Pennsylvania (PA) scores vs Broadkill, Delaware and 150 sites throughout Delaware.
References


Figure 15. Example of low lying marsh with *Nuphar lutea* at John Heinz Wildlife Refuge at Tinicum, PA.