NEW JERSEY SPORTS AND EXPOSITION AUTHORITY

Measurement of Tidal Wetland Impairments

for Acquisition and Enhancement in the New Jersey Meadowlands

MERI, NJSEA

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The main objective of this proposal is to implement existing actions under the current EPA approved NJMC Wetland Program Plan (WPP) (http://water.epa.gov/type/wetlands/wpp.cfm) aimed at measuring ecological function and physical impairments of the 7 selected tidal wetland sites totaling 105 Ha. The main tasks include: the measurements of floral diversity and vegetation cover, high resolution image acquisition/classification, Light Detection and Ranging (LiDAR) image acquisition, hydrological restrictions, tidal exchange and analysis of habitat fragmentation.

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Acronyms frequently used in the text

AC – Anderson Creek

BD – Bellemead Mitigation

CC – Coefficient of Conservatism

CCA – Canonical Correspondence Analysis

FC – Fish Creek Marsh

FQI – Floristic Quality Assessment

HM – Harrier Meadow

HP – Hawk Property

LR – Lyndhurst Riverside Marsh

NJMC – New Jersey Meadowlands Commission

NJSEA – New Jersey Sports and Exposition Authority – formerly NJMC

PSI – Plant Stewardship Index

QAPP – Quality Assurance Project Plan

RB – Riverbend Wetland Preserve

RS – Bellemead Mitigation and Lyndhurst Riverside Marsh

SHS – Secaucus High School Marsh

USACE – U.S. Army Corps of Engineers

USEPA – U.S .Environmental Protection Agency

USFWS – U.S. Fish and Wildlife Service

WPP – Wetland Protection Plan

Introduction

The Hackensack River Estuary is a complex tidal ecosystem in Northern New Jersey once known as one of the most polluted water course in the United States (Shin et al., 2013). This legacy, despite recent developments has significantly impaired the ecological function of some 1,700 acres of remaining tidal wetlands. The main factors driving this impairment are tide restricting structures such as dikes and berms, high levels of contaminates in the sediments, the continuous influx of nitrogen and other nutrients from sewage treatment plants and permitted combined sewer outflows, invasive species, habitat fragmentation by manmade structure (e.g. ditches, roads and railroads), alterations in the hydrology and the filling of wetlands. During the past three decades the New Jersey Meadowlands Commission (NJMC, now NJSEA) has benefited from comprehensive studies and planning documents related to wetland conditions and enhancement in the Hackensack Meadowlands District (District) by Federal and State agencies (USEPA and USACE, 1995; USFWS-USACE-USEPA-NMFS, 2000; USACE, 2003; USACE, 2005 and USACE 2009. These studies conclude that as a first step towards wetland enhancement it is necessary to measure the physical and ecological impairments to ecological function and to perform plant biodiversity assessments. Measuring impairments, identifying quantifiable ecological enhancement success metrics and gathering strategic site information for site selection and assessment of past ecological enhancement projects are also the goals of the EPA approved (2014) NJMC Wetland Program Plan (WPP). This project is designed to measure the physical and ecological impairments of seven open-space sites (Figure 1) and also, to support NJMC's WPP overall objectives which are wetland acquisition, wetland preservation, wetland enhancement, sustainable wetland preservation, and natural resources management.

It would not be practical to measure all possible impairments afflicting these sites, therefore, the types of measurements were carefully selected so that they measure ecosystem functioning and physical process that appropriately explain levels of impairments at each site. Impairments due to chemical pollution are not addressed in this study. Plant species composition and abundance including the presence of invasive species provide an excellent indicator of habitat degradation as demonstrated by studies comparing marsh vegetation in tide-restricted marsh versus tide restored conditions (Barrett and Niering, 1993, Burdick et al., 1997, Artigas and Yang, 2004). Vegetation patterns are also important factors influencing bird and wetland habitat interactions. Aspects of tidal flooding and overall hydrology acting on sites are also good measurable integrative factors that help illustrate degrees of impairment. Examples of measurable attributes in this case include stage duration and frequency, flood and ebb velocities, and hydraulic duty. Finally, microtopography, habitat fragmentation, and connectivity, as well as proximity to legacy land uses such as landfills may also contribute substantially to the assessment of levels of wetland impairment. In this study, we use a combination of traditional field methods with state-of-the-art remote sensing (surface texture and elevation), and in-situ continuous monitoring of water velocities and stage, along with bathymetry measurements. These are employed to characterize floristic assemblages, model wetland and channel topography, determine stage and length of hydroperiods, and measure landscape fragmentation. The final result is an impairment table showing the impairment scores for each site that can be used for planning and management purposes. The report is organized in three broad chapters: 1. - Floral diversity and vegetative cover, 2. - Topography and site hydrology, and 3. - Habitat fragmentation metrics.

Section I - Floral diversity and vegetative cover at selected wetlands

1.1 Introduction

Patterns of diversity of plant communities in an urban tidal marshland

The vegetation of seven sites in the Hackensack Meadowlands District of New Jersey, a brackish tidal estuary, was studied to determine vegetation cover and conservation values. Plots were laid out along an elevation gradient from low marsh through adjacent upland vegetation: low marsh, low to high marsh transition, high marsh, high marsh to upland transition, and upland. The lower marsh habitats are often submerged and the dominant plant species is the native *Spartina alterniflora* (smooth cordgrass). The high marsh is dominated by the native species *Spartina patens* (saltmeadow cordgrass) and *Distichlis spicata* (saltgrass). The high marsh habitat is increasingly invaded by European haplotypes of *Phragmites australis* (common reed). The upland habitats at these sites are dominated by woody plants. The method of nested multiple scale vegetation sampling (Whittaker Plot design) was used, as well as determining vegetation cover, and evaluating conservation value by applying Coefficients of Conservatism values to the analysis. The goals were to understand community-richness and structure in a human-impacted urban marsh and to determine the conservation value of varied plant communities along the gradient from low marsh to upland.

The results show several different trends when correlating vegetation traits to the elevation and marsh gradient. Small-scale plant richness ($1m^2$) increased linearly along transects from low marsh to upland. Large-scale plant-richness ($100m^2$) and beta-diversity increased in a single step from the marsh habitats to upland. Plant cover peaked at the middle of the elevation gradient, at the high marsh habitats. The low to high marsh transition plots exhibited the highest value of Mean of Coefficient of Conservatism, indicating a greater number of species with restrictions to those emergent wetlands at the interface of low and high marsh habitats. Canonical Correspondence Analysis confirms that the gradient in species richness is correlated to the elevation gradient and shows a vegetation cover gradient perpendicular to it. Within both marsh habitats there appears to be a strong gradient of canopy cover that is not correlated to species richness. The mid-elevation habitats exhibit both a higher vegetation cover and more species with higher Conservatism values. Yet this is also the habitat in which the non-native *Phragmites australis* is abundant. This habitat seems to have a potential for harboring marshland-specific native plants, and conservation or ecological enhancement efforts should target it.

Pluchea odorata (Saltmarsh Fleabane): this annual species requires vegetation gaps for establishment. Here an artificial structure is colonized. Riverside July 2, 2014, photo by C. Holzapfel

1.2 Methods

1.2.1 The study sites

Seven sites have been chosen in the District (Figure 1): (1 and 5) Bellemead Mitigation and Lyndhurst Riverside Marsh (treated as one site in the vegetation survey and habitat fragmentation assessment due to their adjacent location), (2) Fish Creek Marsh, (3) Harrier Meadow, (4) Hawk Property, (6) Riverbend Wetland Preserve, and (7) Secaucus High School Marsh. Within each site, the area was observed for its topography and vegetation type, distinguishing three types of habitats (Figure 2): ***low marsh*** – subject to tidal flooding twice a day on most of the days; ***high marsh*** – subject to tidal flooding occasionally, when highest tides occur (twice a month every month or less); ***upland*** – higher elevation are seldom flooded (only in extreme storms), allowing for woody vegetation to grow. Wherever possible, one or two vegetation sampling plots were established in the three habitats: low marsh (L), high marsh (H), and upland (U), and two transition zones, low to high marsh (LH), and high marsh to upland (HU).

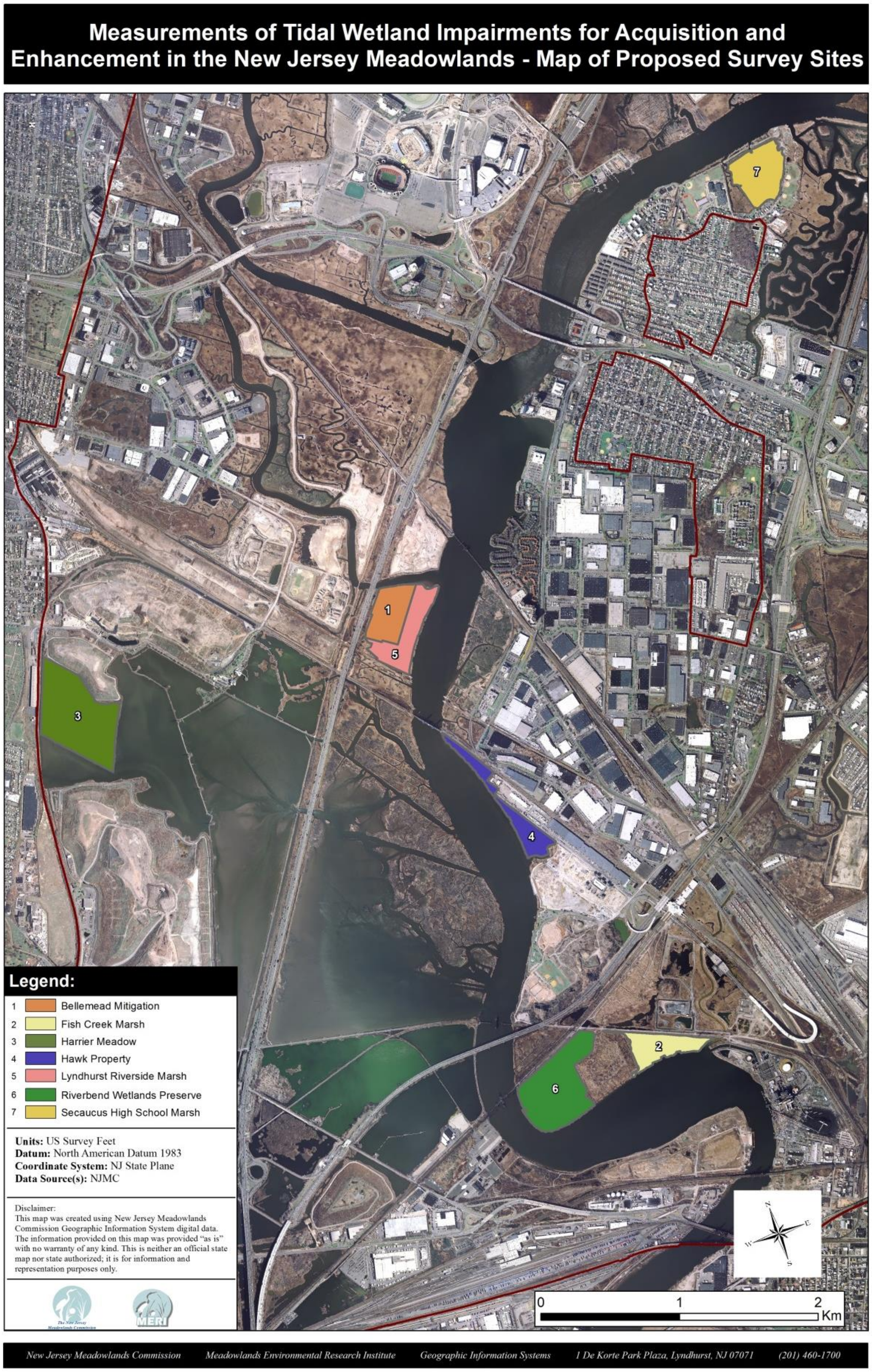


Figure 1 - Satellite image of NJ Meadowlands, showing the survey sites and surrounding municipalities.

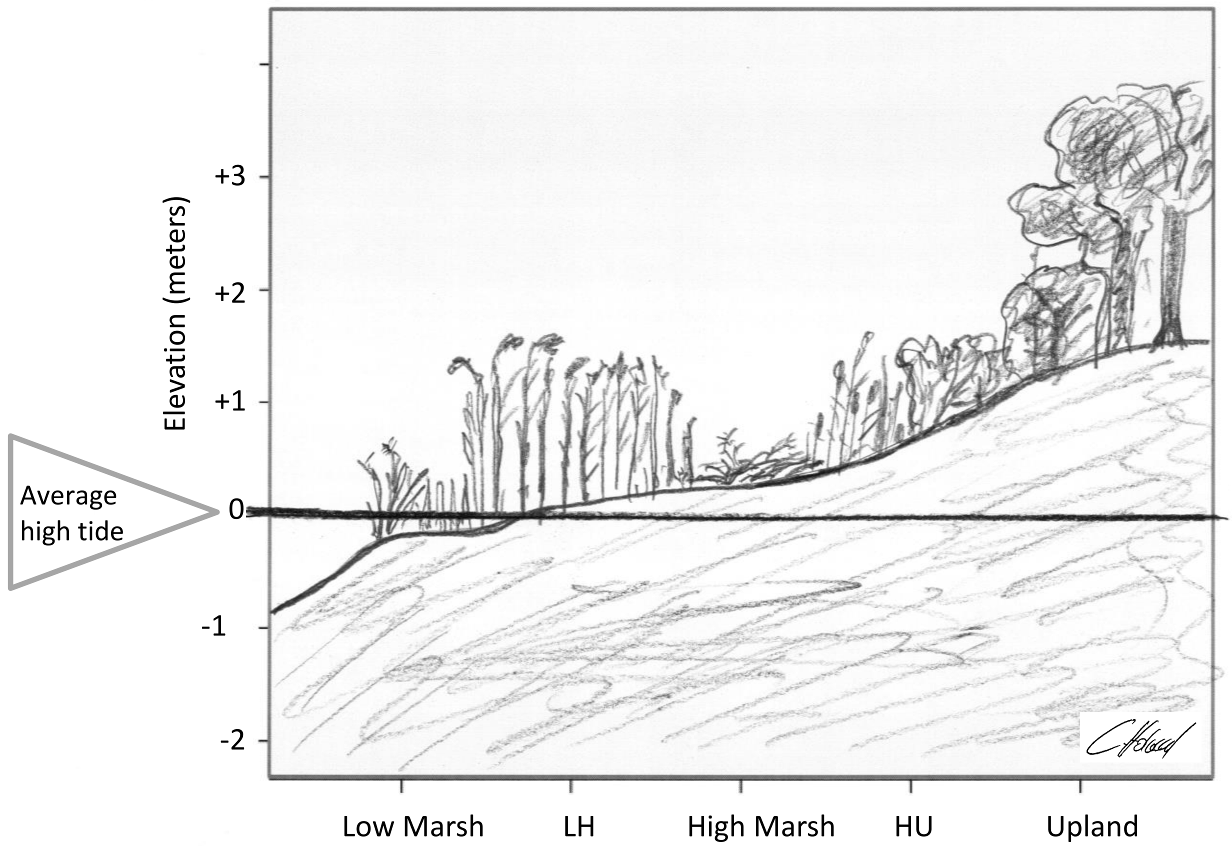


Figure 2 - Vegetation habitats in the tidal Meadowlands

Rectangular plots (1,000 square meters: 20 x 50 meters) were marked on the different habitats, as well as at transition area between these habitats (Figure 3 – Figure 8). The location of the corners of the plots were determined using a Magellan/Ashtech ProMark 2 GPS device with a horizontals accuracy of 30 cm. Table 1 shows plot names and geographic coordinates in decimal degrees of each plot. The method of accessing each site varied from motor boat, by car and foot, or by kayaks.

Figure 3 - Bellemead & Riverside (RS) Whittaker Plot: BMU1 - Bellemead upland, BML1 – Bellemead low marsh, BMH1 – Bellemead high marsh, RSLH1 – Riverside low to high marsh transition, RSH1 – Riverside high marsh

Figure 4 – Fish Creek (FC) Whittaker Plot: FCLH – transition zone, FCH1 – high marsh, HUFCHU1 – high marsh to upland transition, FCU1 - upland

Figure 5 - Harrier Meadow (HM) Whittaker Plot: HMH1 – high marsh, HMU1 – upland, HUHMHU1 – high marsh to upland transition, HMH2 high marsh

Figure 6 - Hawk Property (HP) Whittaker Plot: HPU1 – upland, HPLH1 – low to high marsh transition, HPH1 – high marsh

Figure 7 - Riverbend (RB) Whittaker Plot: RBH1 – high marsh, RBH2 – high marsh, RBL1 – low marsh, RBLH1 – low to high marsh transition

Figure 8 - Secaucus High School Marsh (SH) Whittaker Plot: SHH1 – high marsh, SHL1 – low marsh, SHLH1 – low to high marsh transition, SHL2 – low marsh, SHH2 – high marsh

Site	Plot Code	Habitat type	Location of 0,0 corner	*another corner	Latitude	Longitude
Bellemead-Riverside	BM-L1	L	SW		40.78591667	-74.09001667
Bellemead-Riverside	BM-H1	H	SE		40.78500000	-74.08900000
Bellemead-Riverside	BM-U1	U	NW		40.78733333	-74.08983333
Bellemead-Riverside	RS-LH	LH	SW		40.78325000	-74.08940000
Bellemead-Riverside	RS-H1	H	SE		40.78280000	-74.08941667
Fish Creek	FC-LH	LH	NE		40.75311667	-74.08056667
Fish Creek	FC-H1	H	SE		40.75253333	-74.08011667
Fish Creek	FC-HU	HU	SW	NE	40.75283333	-74.07846667
Fish Creek	FC-U1	U	SW		40.75211667	-74.07811667
Harrier Meadow	HM-H1	H	NW		40.78890000	-74.11913333
Harrier Meadow	HM-H2	H	SE		40.78691667	-74.11740000
Harrier Meadow	HM-HU	HU	NW		40.78773333	-74.11846667
Harrier Meadow	HM-U1	U	SE		40.78773333	-74.11820000
Hawk Property	HP-LH	L	NE		40.76963333	-74.08560000
Hawk Property	HP-H1	H	SE		40.76905000	-74.08531667
Hawk Property	HP-U1	U	SE		40.77240000	-74.08678333
Riverbend	RB-L1	L	NE		40.75146667	-74.08976667
Riverbend	RB-LH	LH	SE		40.75086667	-74.08961667
Riverbend	RB-H1	H	NE	NW	40.75100000	-74.09171667
Riverbend	RB-H2	H	SW		40.75306667	-74.09340000
Secaucus High School	SH-L1	L	NW		40.80503333	-74.04531667
Secaucus High School	SH-L2	L	SE		40.80471667	-74.04578333
Secaucus High School	SH-LH	LH	SE	NE	40.80530000	-74.04691667
Secaucus High School	SH-H1	H	SE		40.80535000	-74.04533333
Secaucus High School	SH-H2	H	NW		40.80473333	-74.04565000

Table 1 Location of plots and habitat type: L - low, H - high, U - upland; and the transition areas: LH and HU. Location of plot corner (0,0) is in compass direction relative to the locations of the other corners. Latitude and longitude (decimal degrees) indicate plot corner (0,0).
*If the zero corners could not be measured, the location and coordinates of an alternative corner is given.

1.2.2 Vegetation sampling

Permanent species richness plots (so-called Whittaker plots) were delineated to assess and monitor small and large scale diversity structure of the plant communities were established. The Diversity Plot Technique after Whittaker (Shmida, 1984; Stohlgren et al., 1995) describes species-area relations for a vegetation unit. For the most efficient determination of these, the sample employs tenfold rather than doubling expansions of the area, and it uses a combination of $1m^2$ plots and larger rectangles of increasing size. In addition to describing and documenting the vegetation structure, such a nested design allows for the accurate measurement of both small scale (1 to 10 m^2) and large scale (100 to 1,000 m^2) diversity as well as their relationship to each other (α- and β-diversity) (Shmida & Wilson, 1985). Whittaker plots are being used increasingly in a wide range of vegetation types and therefore allow comparisons of diversity structure across a wide range of ecosystems (Stohlgren, 2006). This method was modified by scattering the 1 m^2 plots throughout the plot, rather than keeping them adjacent to each other, in order to avoid misinformation due to patchiness of the vegetation (Figure 9).

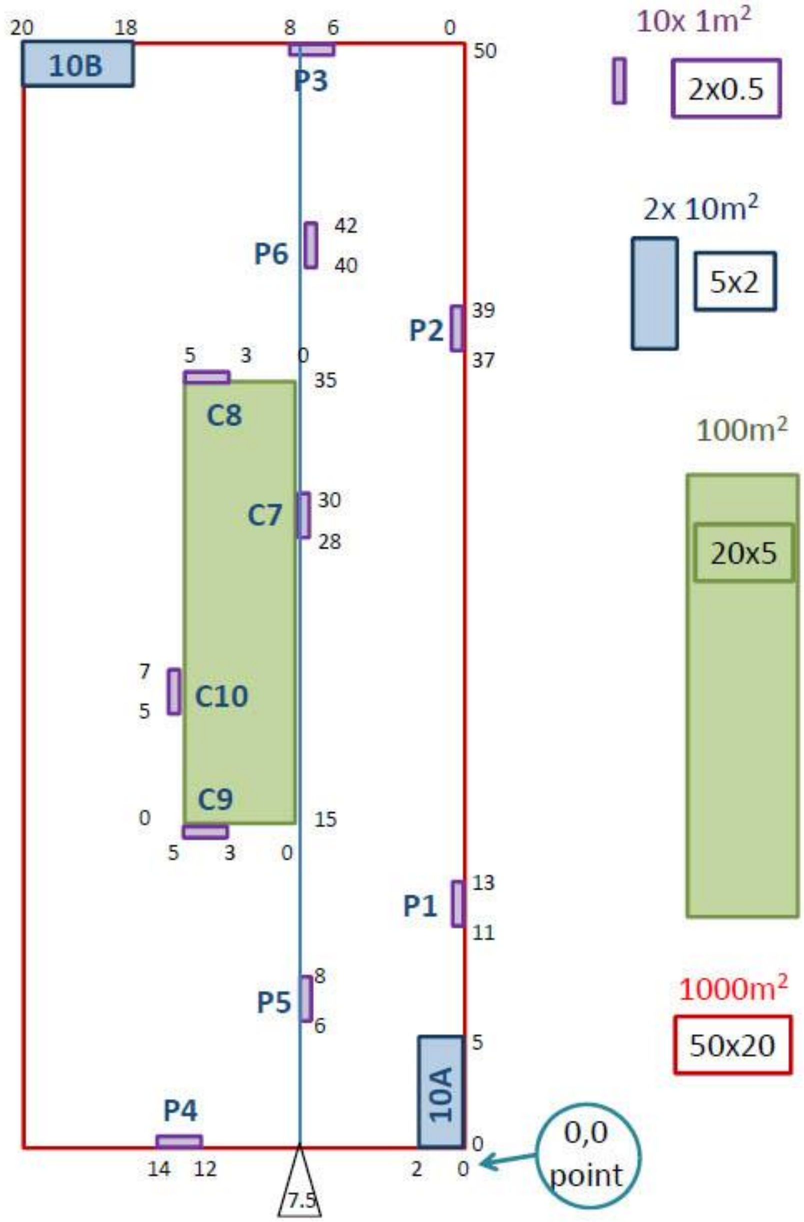


Figure 9 Whittaker plot set-up. Nested design has been modified to allow for sampling 1 m^2 subplots scattered throughout the 1000 m^2 plot. The diagram shows the location of the sub-plots within the 1000 m^2 plot. The colored rectangles are sub-plots. The numbers in small font show the distance (m) from a corner to the location of a sub-plot.

Plant cover on each small-scale quadrat (1 m^2) was estimated, as well as cover of each of the species and measured as Leaf Area Index (LAI - leaf area covered per base area) using LICOR LAI-2000. LAI values have been measured in the non-upland plots, since this method requires referring the reading under the vegetation to a reading of full light. This was not possible to do in the upland plots, where the vegetation cover is high and the plants are tall. It is not possible to reach an uncovered upland location within the time lapse required from the reading taken under the vegetation.

The vegetation data was collected from June 30 to July 16, 2015. The LAI measurements were taken from August 19 to 26, 2014 (Table 2).

Site	**Plot Code**	**Habitat type**	**vegetation census date**	**LAI date**
Bellemead-Riverside	BM-L1	L	7/16/2014	8/19/2014
Bellemead-Riverside	BM-H1	H	7/1/2014	8/19/2014
Bellemead-Riverside	BM-U1	U	7/16/2014	
Bellemead-Riverside	RS-LH	LH	7/1/2014	8/19/2014
Bellemead-Riverside	RS-H1	H	7/1/2014	8/19/2014
Fish Creek	FC-LH	LH	7/8/2014	8/22/2014
Fish Creek	FC-H1	H	7/8/2014	8/22/2014
Fish Creek	FC-HU	HU	7/2/2014	
Fish Creek	FC-U1	U	7/2/2014	
Harrier Meadow	HM-H1	H	6/30/2014	8/21/2014
Harrier Meadow	HM-H2	H	6/30/2014	8/21/2014
Harrier Meadow	HM-HU	HU	6/30/2014	
Harrier Meadow	HM-U1	U	6/30/2014	
Hawk Property	HP-LH	L	7/10/2014	8/21/2014
Hawk Property	HP-H1	H	7/10/2014	8/21/2014
Hawk Property	HP-U1	U	7/10/2014	
Riverbend	RB-L1	L	7/11/2014	8/22/2014
Riverbend	RB-LH	LH	7/11/2014	8/22/2014
Riverbend	RB-H1	H	7/11/2014	8/22/2014
Riverbend	RB-H2	H	7/11/2014	8/22/2014
Secaucus High School	SH-L1	L	7/7/2014	8/20/2014
Secaucus High School	SH-L2	L	7/7/2014	8/26/2014
Secaucus High School	SH-LH	LH	7/7/2014	8/26/2014
Secaucus High School	SH-H1	H	7/7/2014	8/20/2014
Secaucus High School	SH-H2	H	7/7/2014	8/26/2014

Table 2. Sample dates of plots habitat type of plots: L - low, H - high, U - upland; and the transition areas: LH between low and high marsh, HU - between high marsh and upland; date Leaf Area Index (LAI) data collected

Plants were identified and vouchers of most of them collected and preserved in a plant press. These will be deposited in the reference collection at Rutgers Newark/Fusion Ecology Lab. Plant names follow Quality Assurance Project Plan (QAPP) and are based primarily on Weakley (2012) and the Flora of North America (2014).

1.2.3 Data analysis

Data on small-scale (1 m^2) and large scale (1,000 m^2) richness and species-area increase function (d, the rate at which species [S] are added when increasing plot size [A]: S= b = d * log A) were plotted for the habitat gradient using a boxplots procedure (SPSS Vs. 21, IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0 Armonk, NY: IBM Corp.).

The Plant Stewardship Index (PSI) is a modification of the Floristic Quality Assessment (FQI) methodology that incorporates the presence and impact of non-native plants on the calculation. The numerical difference between the FQI and the PSI indicates the impact of non-natives on the site's quality. The Mean C is the average index number of all the assigned numbers of plants found on the site. Native Mean C = Sum of Coefficients / N and Total Mean C = Sum of Coefficients / N + I, where N = Number of native species and I = Number of Introduced species (Bowman's Hill Wildflower Preserve, 2006). Verbal equivalents for the Native Mean C Values are the following:

- Severely Degraded Area for a Native Mean C = 0 – 2.4;
- Degraded Natural Area for a Native Mean C = 2.5 – 3.4;
- Quality Natural Area for a Native Mean C = 3.5 – 4.4;
- High Quality Natural Area for a Native Mean C = 4.5 – 5.4; and
- Exceptional Quality Natural Area for a Native Mean C = 5.5.

The calculated Mean C is the most meaningful measure of the habitat quality and is not dependent on the size of the survey area. PSI is a standardized assessment tool that calculates a numerical index reflecting the quality of native plant communities. The lists of plants from each of the survey sites were recorded and entered into online PSI forms (Bowman's Hill Wildflower Preserve, 2006) for each specific site. An online calculator at that website computed several measures of states of being natural or disturbed that can be used to determine a relative value of each study area. The PSI assigns relative values to every plant found within a study area, and then calculates an overall value for each study area.

The PSI is based on the Floristic Quality Assessment methodology that uses a Coefficient of Conservatism (CC) between 0-10 and the assignment of coefficients is defined by Bowman's Hill Wildflower Preserve (2006) as the follows:

0 to 3: plants with a high range of ecological tolerances/found in a variety of plant communities;
4 to 6: plants with an intermediate range of ecological tolerances/associated with a specific plant community;
7 to 8: plants with a poor range of ecological tolerances/associated with advanced successional stage; and
9 to 10: plants with a high degree of fidelity to a narrow range of pristine habitats.

The plants that are ranked with a lower coefficient are the ones that can be found in a broader range of habitats, usually disturbed areas. Non-native species are always assigned a score of 0. Plants that are ranked with higher numbers are those species that need a more stable habitat and native plant community. These are the species of greatest concern because they are being lost. The mean CC was calculated for plants in each of the habitat types.

Vegetation structure and composition in relation to environmental factors (predictors) for the 1 m^2 plots were explored using Canonical Correspondence Analysis (CCA) (Canoco Vers. 4.5, 2002). Environmental factors considered were measured Leaf Area Index, estimated cover, plot richness, and relative position along the habitat gradient. The derived ordination diagrams of the first two axes (see Figures 10 to 12) show the scores of species and environmental factors. For species scores the distance between the symbols in the diagram approximates the dissimilarity of distribution of relative abundance of those species across the samples as measured by their chi-square distance. Environmental factor arrows show the expected direction in which the factor increases while relative length indicates the magnitude of influence of the factor. In addition, the angles between arrows indicate correlations between individual environmental factors (e.g., 180 degrees indicates negative correlation). Species scores can be projected perpendicularly onto the arrow line of a given environmental variable and indicate the estimated optima of individual species of that environmental variable.

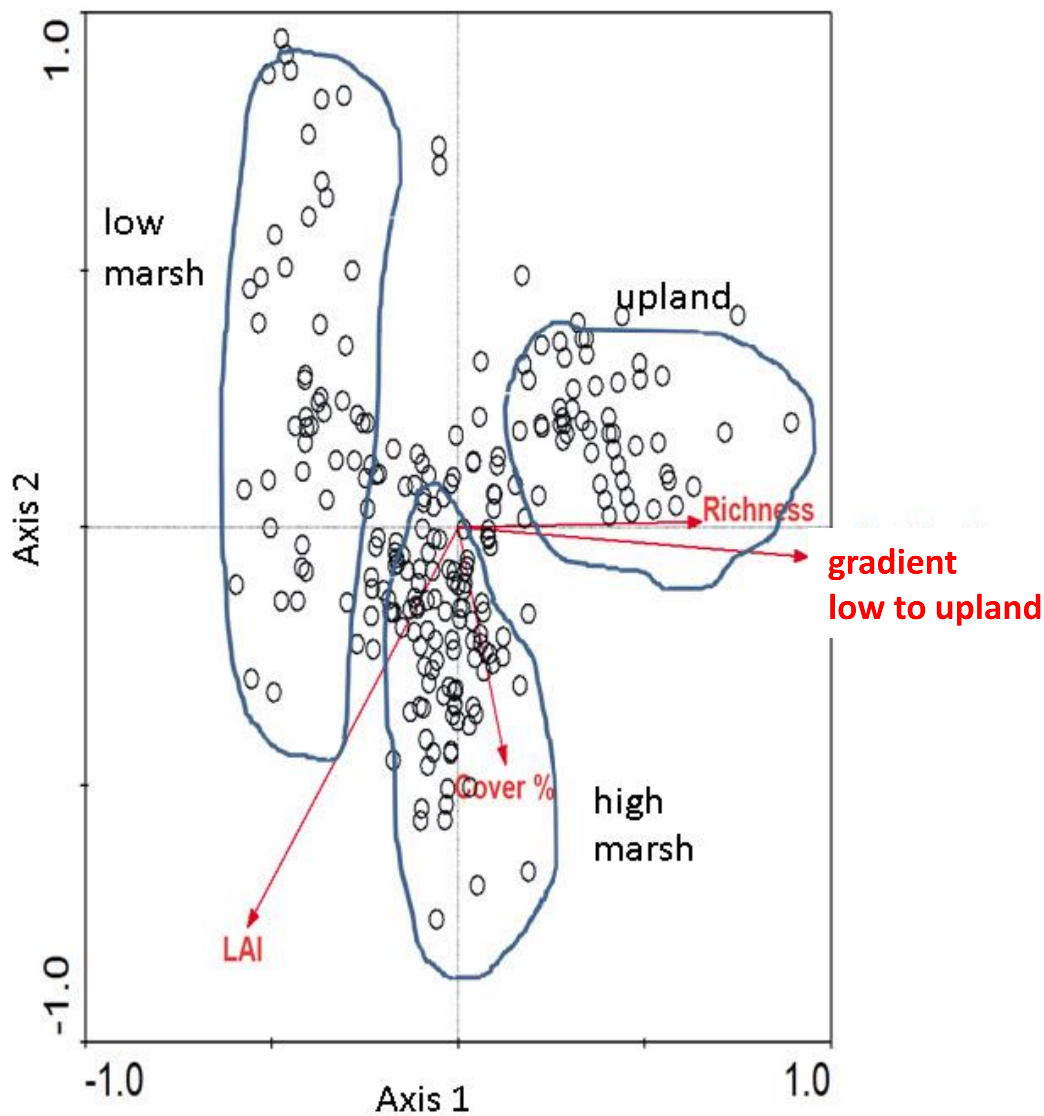
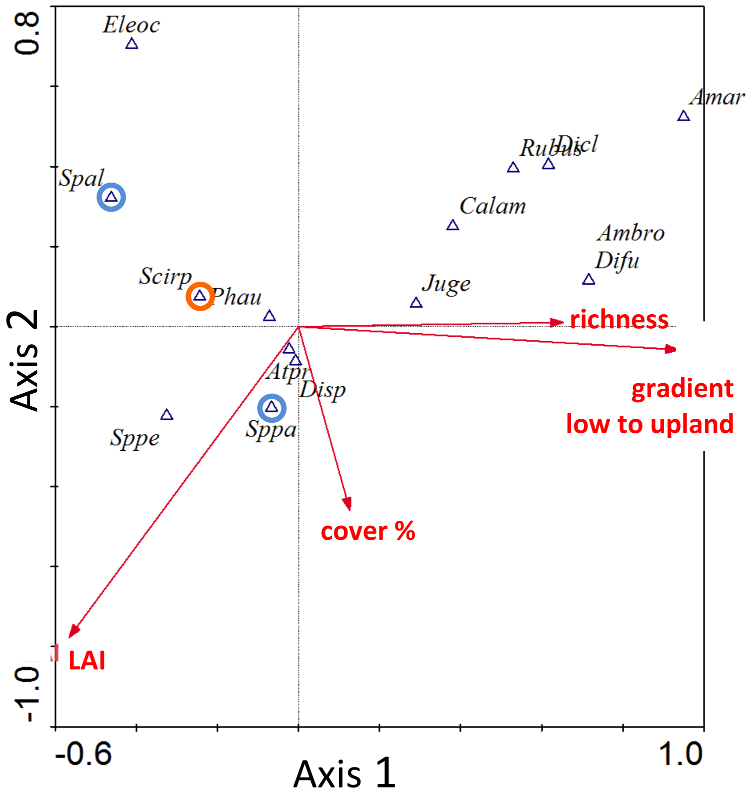


Figure 10 Ordination diagram of the vegetation of 1 m^2 plots based on Canonical Correspondence Analysis (CCA) in relation to predictors (arrows): richness (number of species per plot; LAI- measured Leaf Area Index; cover %- estimated vegetation cover; gradient- from low marsh to upland. Eigenvalues for horizontal and vertical CCA axes are 0.552 and 0.405, respectively.



code	plant name
Amar	*Ambrosia artemisiifolia*
Ambro	*Ambrosia trifida*
Atpr	*Atriplex prostrata*
Calam	*Calamagrostis epigejos*
Dicl	*Dichanthelium clandestinum*
Difu	*Dipsacus fullonum*
Disp	*Distichlis spicata*
Eleoc	*Eleocharis parvula*
Juge	*Juncus gerardii*
Phau	*Phragmites australis*
Rubus	*Rubus sp.*
Scirp	*Scirpus sp.*
Spal	*Spartina alterniflora*
Sppa	*Spartina patens*
Sppe	*Spartina cynosuroides*

Figure 11 Ordination diagram of the plant species scores based on Canonical Correspondence Analysis (CCA) in relation to predictors (arrows): species richness per plot; LAI- measured Leaf area Index; cover %- estimated vegetation cover; gradient: from low marsh to upland. Eigenvalues for horizontal and vertical CCA axes are 0.552 and 0.405, respectively.

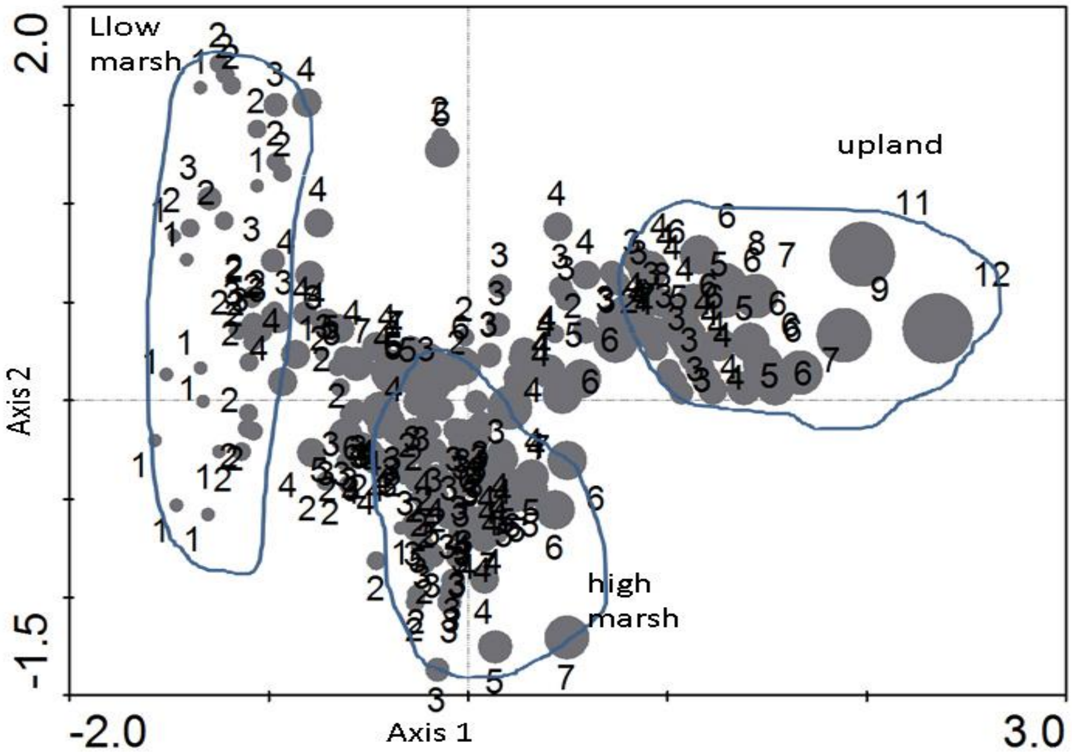


Figure 12 Ordination diagram of plots in relation to species richness based on Canonical Correspondence Analysis (CCA) Eigenvalues for horizontal and vertical CCA axes are 0.552 and 0.405, respectively.

1.3 Results

1.3.1 Riverbend Wetlands Preserve (Riverbend)

Native Mean C – 6.3
Total Mean C – 5.5
Floristic Quality – 16.6
Plant Stewardship Index – 14.6

The survey areas at Riverbend are made up of high and low marsh. The high marsh is growing with a mixture of *Spartina patens* (saltmeadow cordgrass) and *Distichlis spicata* (saltgrass). *Salicornia depressa* (common glasswort) grows in large dense stands as a dominant plant in a few areas around the marsh. *Spartina alterniflora* (smooth cordgrass) grows in the low marsh and near the river, but is beginning to grow as a mixture in the high marsh. This site had six species recorded which is the least amount of species recorded per site of all of the survey sites, however this site is high in species richness. *Phragmites australis* (common reed) is the dominant vegetation growing as a dense monoculture around the site. Few *P. australis* plants can be observed in the survey locations growing as a single plant or a small cluster of plants. Overall this site is ranked an Exceptional Quality Natural Area and received the highest Native Mean C of 6.3.

1.3.2 Secaucus High School Marsh (Secaucus)

Native Mean C – 5.8
Total Mean C – 4.9
Floristic Quality – 19.3
Plant Stewardship Index – 16.3

The Secaucus High School Marsh is a restored site completed in 2007. Before ecological enhancement, the site was covered by a monoculture of *P. australis* with some *S. alterniflora*. Enhancement to the site included *P. australis* management, reducing marsh elevation to improve tidal flow, constructing and improving tidal channels, and planting native species to establish low marsh, high marsh, transition, and upland vegetative communities. The goal of the enhancement was to increase plant biodiversity and improve tidal flow. The majority of the site consists of a low marsh habitat covered by S*. alterniflora*. *Amaranthus cannibinus* (salt-marsh water-hemp) often grows as a mixture of vegetation with *S. alterniflora*. There are two distinct high marsh areas in the northeast part of the site. *Spartina patens* and *D. spicata* generally dominate these areas with multiple mixtures of other plant species: *A. cannibinus*, *Juncus gerardii* (black grass), *Spartina cynosuroides* (big cordgrass), and *Solidago sempervirens* (seaside goldenrod). This is the only survey site with larger stands of *S. cynosuroides*. A few other sparsely distributed plants were also observed growing on the high marsh: *Eleocharis parvula* (little-spike spikerush), *Rumex crispus* (curly dock), and *S. depressa*. Secaucus is routinely managed for invasive species. This site is ranked as an Exceptional Quality Natural Area and calculated to be a Native Mean C of 5.8.

1.3.3 Fish Creek Marsh (Fish Creek)

Native Mean C – 4.5
Total Mean C – 33.5
Floristic Quality – 18.4
Plant Stewardship Index – 114.2

The surveys at Fish Creek Marsh are made up of high marsh, low marsh and a small upland hill. The site is surrounded by a dense monoculture of *P. australis*. Twenty-six species were recorded at Fish Creek. The areas of high marsh are dominated by a mixture of *D. spicata* and *S. patens* with a few *P. australis* plants. *Iva frutescens* (maritime marsh-elder) grows sparsely on the high marsh and some *S. depressa* was observed. Near the base of the hill at the transition from the high marsh *Morella pensylvanica* (northern bayberry), *Panicum virgatum* (switchgrass), *Baccharis halimifolia* (groundsel tree), *Rhus copallinum* (winged sumac) and *P. australis* formed a dense area of vegetation. In addition, more weedy species like *Ailanthus altissima* (tree-of-heaven), *Morus alba* (white mulberry), *Phytolacca americana* (American pokeweed), *Ampelopsis brevipedunculata* (*porcelain berry)*, *Lonicera morrowii* (Morrow's honeysuckle), and *Parthenocissus quinquefolia* (Virginia creeper) can be found growing on the hill. The Fish Creek site was the location where *Scutellaria nervosa* (veined skullcap) was found. *Scutellaria nervosa* has a coefficient of 10 and is also ranked a critically imperiled species.

The high marsh area at this site could be described similarly to Riverbend. The high marsh area has a mixture of typical high marsh vegetation of a few species with high coefficients. The areas of low marsh are smaller and grow only in the fringes of the site near the river and creeks. If the site were void of the small upland hill where species identified have lower coefficient, it is likely that this site would have calculated to be a higher native mean. This site is ranked a High Quality Natural Area and calculated to be a Native Mean C of 4.5.

1.3.4 Harrier Meadow (Harrier)

Native Mean C – 3.6
Total Mean C – 2.3
Floristic Quality – 18.2
Plant Stewardship Index – 11.7

Harrier Meadow is a 77 acre site located on the western edge of the District and is the only site in the survey that was not located along the Hackensack River. Only a portion of the site was ecologically enhanced. Ecological enhancement activities of approximately 50 acres of the marsh began in 1998 with the excavation of channels and impoundments and the creation of several upland islands. Before enhancement, the site was dominated by *P. australis* and *Lythrum salicaria* (purple loosestrife) with small areas of high marsh supporting *D. spicata*, *S. patens*, and *J. gerardii*.

Harrier is a mixture of high marsh and meadows with a few areas of low marsh. The high marsh community is growing with *D. spicata*, *J. gerardii*, *Pluchea odorata*, (saltmarsh fleabane), *Solidago sempervirens*, and *S. patens*. Other native species that were common, but not dominating included *Hibiscus moscheutos* (swamp rose-mallow), and *Atriplex prostrata* (thinleaf orach), *Eleocharis parvula*, *I. frutescens*, and *J.effusus* (soft rush). *Spartina alterniflora* can be found growing in the high marsh or along the channels and creeks as a few plants to some dominant clusters.

The upland area surveyed is located in the area of the high marsh. The woody component of the upland and its transition to scrub-shrub is a composed mostly of *Ailanthus altissima*, *Morus alba*, *Juniperus virginiana* (eastern red cedar) *Baccharis halimifolia*, *Phytolacca americana*, *Ageratina altissima* (common white snakeroot), and *Cirsium arvense* (Canada thistle), *Lonicera morrowi*, (Morrow's honeysuckle), *Parthenocissus quinquefolia*, *Rumex crispus*, *Solanum dulcamara* (bittersweet nightshade), and *Toxicodendron radicans* (poison ivy). *Asparagus officinali*, (asparagus) was also found in the survey area, but was not found here in the past.

Phragmites australis grows as a dense monoculture around the unenhanced parts of the site. It can also be found growing in places that were surveyed growing as either single plants or in small dense clusters of plants. *Phragmites australis* also grows as a dense mixture with *B. halimifolia* in the eastern side of the site. This site is ranked a Quality Natural Area and calculated to be a Native Mean C of 3.6.

1.3.5 Bellemead Mitigation and Lyndhurst Riverside (Riverside)

Native Mean C – 3.4
Total Mean C – 2.6
Floristic Quality – 15.7
Plant Stewardship Index – 11.8

Bellemead Mitigation and Lyndhurst Riverside Marsh are adjacent to each other. Lyndhurst Riverside Marsh is located along the banks of the Hackensack River and both sites are separated by a narrow ditch. The upland area is adjacent to Bellemead. It is separated by a narrow ditch and the New Jersey Turnpike. Both sites have small patches of high marsh and some low marsh. Bellemead was enhanced in 1990 and a small area of the Lyndhurst Riverside Marsh was enhanced in 1994.

Phragmites australis was the dominant plant with few areas of *S. alterniflora* growing along the edges near the creek and ditches. Enhancement consisted of planting *S. alterniflora* in the low marsh and *D. spicata* and *S. patens* in the high marsh. *Phragmites australis* has reinvaded the Bellemead site and only a few small patches of high marsh can be observed. *Amaranthus cannibinus*, *E. parvula*, and *S. depressa* are three other plants that can be found interspersed in the survey area. The Lyndhurst Riverside Marsh is also dominated by *P. australis*, but various size patches of *S. patens* and *D. spicata* can be found. There were a few small unvegetated areas on top of the marsh surface. *Eleocharis parvula* was the dominant species that could be observed growing there and also a few single *S. depressa* plants could be observed.

The upland area surveyed was growing with mostly invasive plants: *Ailanthus altissima*, *Paulownia tomentosa* (empress tree), *Celastrus orbiculatus* (Oriental bittersweet), *Lonicera morrowii*, *Daucus carota* (Queen Anne's lace), *Polygonum perfoliatum* (mile-a-minute vine), and *P. australis*. Other plants growing there had a lower coefficient or a coefficient of 0 including: *Oxalis stricta* (yellow wood-sorrel), *Prunus serotina* (black cherry), *Sambucus canadensis* (common elderberry), *Phytolacca americana*, *Polygonum scandens* (climbing false buckwheat), *Ageratina altissima*, *Eupatorium serotinum* (late thoroughwort), *Toxicodendron radicans* (poison ivy); and three species of goldenrods *Solidago canadensis* (Canada goldenrod), *Solidago rugosa* (wrinkle-leaf goldenrod), and *Solidago sempervirens* (seaside goldenrod).

Bellemead Mitigation has not been managed since the completed ecological enhancement. *Phragmites australis* has reinvaded the high marsh and low marsh. Large dense stands of *S. alterniflora* can still be observed growing around the site and along the creeks; while the Lyndhurst Riverside Marsh has very little viable high marsh left and that is including where the plants are growing as a mixture with *P. australis*. This site is ranked a Degraded Natural Area and calculated to be a Native Mean C of 3.4.

1.3.6 Hawk Property (Hawk)

Native Mean C – 3.4
Total Mean C – 2.0
Floristic Quality – 16.5
Plant Stewardship Index – 9.5

The Hawk Property is a narrow triangular shape bordered between the Hackensack River and County Road Extension. The survey area is made up of an upland area, high marsh and a narrow area of low marsh. In the high marsh plant community consists of *D. spicata* and *S. patens* are the dominant vegetation with some *Pluchea odorata* (sweet-scented camphorweed), *Solidago sempervirens*, and *Atriplex prostrata*. *P. australis* forms a dense border at the north and south of the property. *P. australis* is growing inward towards the high marsh gradually changing from a dense monoculture to fewer plants that can be found there. Along most of the river's edge is a strip of *S. alterniflora* but not before it transitions to a thick stand of *P. australis*.

The upland area is a hill probably the result of fill material from the railroad or trucking company adjacent to the property. The mixtures of vegetation are weedy and invasive. More than half the species surveyed at Hawk are plants with coefficients that have a 0 and these species are all found in the upland: *Achillea millefolium* (yarrow), *Ailanthus altissima*, *Robinia pseudoacacia* (black locust), *Alliaria petiolata* (garlic mustard), *Allium vineale* (field garlic), *Artemisia vulgaris* (mugwort), *Ampelopsis brevipedunculata* (porcelain berry), *Asparagus officinalis* (asparagus), *Bromus japonicas* (Japanese chess), *Daucus carota* (Queen-Anne's-Lace), *Dipsacus fullonum* (teasel), *Solanum dulcamara* (bittersweet nightshade), *Lythrum salicaria* (purple loosestrife), *Melilotus officinalis* (yellow sweet clover), *Rosa multiflora* (multiflora rose), *Rumex crispus*, *Lonicera japonica* (Japanese honeysuckle), and *Lonicera morrowii* (Morrow's honeysuckle), *Oxalis stricta* (common yellow wood sorrel), *P. australis*, and *Verbascum thapsus* (common mullein). *Ambrosia Artemisia* (ragweed) is assigned a coefficient of 0, but not invasive.

And still there were more plants identified that had a lower assigned coefficient as well which included: *Acer negundo* (box elder), *Ambrosia trifida* (giant ragweed), *Rhus copallinum* (winged sumac), *Solidago canadensis* (Canada goldenrod), *Solidago sempervirens* (seaside goldenrod), *Toxicodendron radicans*, and *Parthenocissus quinquefolia*. The remaining species which accounted for approximately a quarter of the rest of the upland species identified had assigned coefficients ranging from 4 through 9. Species found in the uplands only and not in the low marsh or high marsh were *Carex vulpinoidea* (common fox sedge), *Hibiscus moscheutos* (swamp rose mallow), *Calystegia sepium* (hedge bindweed), *J. gerardii*, and *I. frutescens*.

The remaining species are those that were similarly found in the high marsh or low marsh and have higher coefficients. They are growing as mixtures in some places or where the transition areas overlap. This survey area yielded the most species identified, but they were mainly found in the upland area.

A species of concern that was identified at this site and not the other survey sites, but could be found sparsely growing in other areas around the meadowlands was *Juncus torreyi* (Torrey's Rush). It is ranked (S1) critically imperiled on the Plant Stewardship Index. Without the upland portion survey at this site it would presumably have calculated to be a higher Native Mean. This site is ranked a Degraded Natural Area and calculated to be a Native Mean C of 3.4.

Of all of the sites surveyed none receive the lowest designation for Native Mean C Value listed as Severely Degraded Area between 0-2.4. All of the sites surveyed and the species lists generated by the Plant Stewardship Index calculated in an orderly arrangement from Degraded Natural Area to the most Exceptional Quality Natural Area.

Two survey sites generated the same Native Mean C Value of 3.4 that is defined as a Degraded Natural Area they were Riverside and Hawk. Both sites had survey plots in an upland, high marsh and low marsh area. Hawk had more species listed than Riverside did. Of all species listed, half were invasive having a coefficient of 0. Had the upland area and the species that were found there not included in the calculator this site would have a higher Native Mean C Value. By using only the plants found in the high and low marshes the Native Mean C Value would have increased to a higher quality site. The acreage of high marsh at Hawk is also much larger than at Riverside. However, the low marsh at Riverside is larger than the high marsh area at Hawk.

The Harrier Meadow site surveys include high marsh and transitional uplands, but no low marsh. The plant species list was the second largest to Hawk, but the amount of invasive plants identified was less. The Harrier Meadow Native Mean C Value was 3.6 and is defined as a Quality Natural Area. Harrier also has the second largest invasive species plant list most of which are found in the upland survey area. The only difference from Hawk and Riverside is that while *P. australis* has been the common invasive species found in all of the plotted areas; at Harrier Meadow *Lythrum salicaria* (purple loosestrife) was found in all of its survey areas and *Melilotus officinalis* (yellow sweet clove) was found in the high marsh area.

The Fish Creek site surveys include high marsh, uplands and transitional areas. The Native Mean C Value was 4.8 and is defined as a High Quality Natural Area. The upland is small in comparison to the high marsh area. Fewer invasive plants were identified here. Most of Fish Creek is made up of high marsh. There is very little low marsh area except near the creek. The upland hill is small and the railroad embankment transitions from an upland and weedy area to the high marsh. *P. australis* also forms a dense border around this site.

The final two survey sites and their plant lists both generated a calculation in the range of an Exceptional Quality Natural Area. The Secaucus High School Marsh had a Native Mean C Value of 5.8 and Riverbend Wetlands Preserve had a Native Mean C Value 6.3. Secaucus is a marsh enhancement site. Both sites did not have upland areas to survey; they were surveyed for low marsh, high marsh and high/low marsh areas. The plant list for Secaucus High School Marsh was twice as long as Riverbend Wetlands Preserve. Both sites have *P. australis* with a coefficient of 0 found in all three areas just as the other sites did. However, Secaucus High School Marsh had two additional species with a coefficient of 0 that were only found on the high marsh they were *Rumex crispus* and *Persicaria lapathifolia* (dock-leaved smartweed). Riverbend had the least amount of species found only eight identified plants. But, this high marsh area is larger than the rest of the sites surveyed.

The mid-elevation habitat, high marsh, exhibits both greater vegetation cover and more species with higher CC values (Table 3). This indicates that many of the species growing in the high marsh are restricted to this wetland habitat. Yet this is also the habitat in which the non-native *P. australis* is present in greatest abundance. This habitat seems to have a potential for harboring marshland-specific native plants, and conservation and ecological enhancement efforts should target it.

Habitat	**Mean of Coefficient of Conservatism**	**standard error (SE)**
low marsh	4.83	0.80
low to high marsh transition	5.46	0.69
high marsh	4.00	0.68
high marsh to upland transition	2.44	0.45
Upland	1.75	0.30

Table 3 Mean Coefficient of Conservatism values by habitat type

1.4 Conclusions

1.4.1 Flora

A list of all plants found in the survey is listed in Table 4, a total of 79 species and 20 additional taxa that to date could not be identified to species have been found in the survey in 2014. A list of plants in each of the sites, showing which habitat they were found in appears in Table 5 - 10.

genus	species	family	common name	NJ-CC	duration	growth habit	native/ exotic
Acer	*negundo*	Aceraceae	box elder	2	P	T	n
Acer	*saccharinum*	Aceraceae	silver maple	5	P	T	n
Achillea	*millefolium*	Asteraceae	common yarrow	0	P	F	x
Ageratina	*altissima*	Asteraceae	common white snakeroot	3	P	F	n
Agrostis	sp.	Poaceae	bent grass			G	
Ailanthus	*altissima*	Simaroubaceae	tree-of-heaven	0	P	T	x
Alliaria	*petiolata*	Brassicaceae	garlic mustard	0	A, B	F	x
Allium	*vineale*	Amaryllidaceae	field garlic	0	P	F	x
Amaranthus	*cannabinus*	Amaranthaceae	saltmarsh water-hemp	7	P	F	n
Ambrosia	*artemisiifolia*	Asteraceae	common ragweed	0	A	F	n
Ambrosia	*trifida*	Asteraceae	giant ragweed	2	A	F SS	n
Ampelopsis	*brevipedunculata*	Vitaceae	porcelain-berry	0	P	V	x
Artemisia	*vulgaris*	Asteraceae	mugwort	0	P	F SS	x
Asparagus	*officinalis*	Amaryllidaceae	asparagus	0	P	F	x
Atriplex	*prostrata*	Chenopodiaceae	thinleaf orach	5	A	F	n
Baccharis	*halimifolia*	Asteraceae	groundsel tree	4	P	SH T	n
Bromus	*japonicus*	Poaceae	Japanese chess	0	A	G	x
Calamagrostis	cf. *epigejos*	Poaceae	bushgrass	0	P	G	x
Calystegia	*sepium*	Convolvulaceae	hedge bindweed	5	P	F V	n
Carex	*vulpinoidea*	Cyperaceae	common fox sedge	4	P	G	n
Carex	sp.	Cyperaceae				G	
Celastrus	*orbiculatus*	Celastraceae	Oriental bittersweet	0	P	V SH	x
Cirsium	*arvense*	Asteraceae	Canada thistle	0	P	F	x
Cirsium	sp.	Asteraceae	thistle			F	
Daucus	*carota*	Apiaceae	Queen Anne's lace	0	B	F	x
Dichanthelium	*clandestinum*	Poaceae	deer-tongue witchgrass	3	P	G	n
Dipsacus	*fullonum*	Dipsacaceae	wild teasel	0	B	F	x
Distichlis	*spicata*	Poaceae	saltgrass	9	P	G	n
Eleocharis	*parvula*	Cyperaceae	little-spike spikerush	9	A, P	G	n
Eupatorium	*serotinum*	Asteraceae	late thoroughwort	1	P	F	n
Fallopia	*scandens*	Polygonaceae	climbing buckwheat	0	P	F V	n
Festuca	sp.	Poaceae	fescue			G	
Fraxinus	*pennsylvanica*	Oleaceae	green ash	4	P	T	n

genus	species	family	common name	NJ-CC	duration	growth habit	native/ exotic
Galium	*aparine*	Rubiaceae	cleavers bedstraw	1	A	F V	n
Hibiscus	*moscheutos*	Malvaceae	swamp rose-mallow	5	A,P	F SS	n
Iva	*frutescens*	Asteraceae	maritime marsh elder	6	P	F SS	n
Juncus	*effusus*	Juncaceae	soft rush	1	P	G	n
Juncus	*gerardii*	Juncaceae	black grass	6	P	G	n
Juncus	*tenuis*	Juncaceae	path rush	1	P	G	n
Juncus	*torreyi*	Juncaceae	Torrey's rush	0	P	G	n
Juniperus	*virginiana*	Cupressaceae	eastern red cedar	2	P	T	n
Lonicera	*japonica*	Caprifoliaceae	Japanese honeysuckle	0	P	V SH	x
Lonicera	*morrowii*	Caprifoliaceae	Morrow's honeysuckle	0	P	SH	x
Lythrum	*salicaria*	Lythraceae	purple loosestrife	0	P	F	x
Melilotus	*albus*	Fabaceae	white sweetclover	0	A, B, P	F	x
Morella	*caroliniensis*	Myricaceae	small bayberry	4	P	T SH	n
Morus	*alba*	Moraceae	white mulberry	0	P	T SH	x
Oxalis	*stricta*	Oxalidaceae	common yellow wood-sorrel	0	P	F	n
Panicum	*virgatum*	Poaceae	switchgrass	3	P	G	n
Parthenocissus	*quinquefolia*	Vitaceae	Virginia creeper	1	P	V	n
Paulownia	*tomentosa*	Paulowniaceae	princess tree	0	P	T	x
Persicaria	cf. *lapathifolia*	Polygonaceae	pale smartweed	0	A	F	n
Persicaria	*perfoliata*	Polygonaceae	mile-a-minute	0	A	F V	x
Phragmites	*australis*	Poaceae	common reed	0	P	G	x
Phytolacca	*americana*	Phytolaccaceae	common pokeweed	0	P	F	n
Pluchea	*odorata*	Asteraceae	saltmarsh fleabane	5	A, P	F SS	n
Poa	sp.	Poaceae	bluegrass			G	
Polygonum or Persicaria	sp.	Polygonaceae				F	
Prunus	*serotina*	Rosaceae	black cherry	1	P	T SH	n
Rhus	*aromatica*	Anacardiaceae	fragrant sumac	4	P	SH	n
Rhus	*copallinum*	Anacardiaceae	winged sumac	2	P	T SH	n
Robinia	*pseudoacacia*	Fabaceae	black locust	0	P	T	n
Rosa	*multiflora*	Rosaceae	multiflora rose	0	P	SS V	x
Rubus	*laciniatus*	Rosaceae	cut-leaved blackberry	0	P	SS V	x
Rubus	sp.	Rosaceae	blackberry		P	SS V	n
Rumex	*crispus*	Polygonaceae	curly dock	0	P	F	x
Rumex	*crispus*	Polygonaceae	dock				
Salicornia	*depressa*	Chenopodiaceae	common glasswort	4	A	F	n
Sambucus	*canadensis*	Caprifoliaceae	common elderberry	2	P	T SH	n
Schedonorus	*pratensis*	Poaceae	meadow fescue		P	G	x
Schoenoplectus	*tabernaemontani*	Cyperaceae	softstem bulrush	6	P	G	n
Scirpus	sp.	Cyperaceae	bulrush			G	n
Scutellaria	sp.	Lamiaceae	skullcap		P	F	n

genus	species	family	common name	NJ-CC	duration	growth habit	native/ exotic
Solanum	*dulcamara*	Solanaceae	bittersweet nightshade	0	P	F V SS	x
Solanum	*nigrum*	Solanaceae	European black nightshade	0	A, P	F SS	x
Solidago	*canadensis*	Asteraceae	Canada goldenrod	2	P	F	n
Solidago	*rugosa*	Asteraceae	wrinkle-leaf goldenrod	2	P	F	n
Solidago	*sempervirens*	Asteraceae	seaside goldenrod	2	P	F	n
Sonchus	*oleraceus*	Asteraceae	common sow-thistle	0	A	F	x
Spartina	*alterniflora*	Poaceae	smooth cordgrass	6	P	G	n
Spartina	*cynosuroides*	Poaceae	giant cordgrass	7	P	G	n
Spartina	*patens*	Poaceae	saltmeadow cordgrass	5	P	G	n
Stuckenia	*pectinata*	Potamogetonaceae	sago-pondweed	3	P	F	n
Toxicodendron	*radicans*	Anacardiaceae	poison ivy	1	P	F SH V SS	n
Typha	*latifolia*	Typhaceae	broadleaf cattail	3	P	G	n
Ulmus	sp.	Ulmaceae	elm		P	T	
Verbascum	*thapsus*	Scrophulariaceae	common mullein	0	B	F	x

Table 4 List of plant species that occurred in the sampled plots. NJ-CC: The Coefficients of Conservatism for New Jersey; Duration: A - annual plant, B - biannual, P - perennial; Growth habit: F - forb, G - graminoid, SH - shrub, SS - subshrub, T - tree, V - vine, M - moss; Native/exotic - n - native, x - exotic

Genus	**species**	**family**	**common name**	**L**	**LH**	**H**	**U**
Ageratina	*altissima*	Asteraceae	common white				U
Ailanthus	*altissima*	Simaroubaceae	tree-of-heaven				U
Amaranthus	*cannabinus*	Amaranthaceae	saltmarsh water-	L			
Atriplex	*prostrata*	Chenopodiaceae	thin-leaf orach		LH		U
Baccharis	*halimifolia*	Asteraceae	groundsel tree				U
Celastrus	*orbiculatus*	Celastraceae	Oriental bittersweet				U
Daucus	*carota*	Apiaceae	Queen Anne's lace				U
Distichlis	*spicata*	Poaceae	saltgrass		LH	H	
Eleocharis	*parvula*	Cyperaceae	little-spike spikerush	L	LH	H	
Eupatorium	*serotinum*	Asteraceae	late thoroughwort				U
Fallopia	*scandens*	Polygonaceae	climbing buckwheat				U
Juncus	*gerardii*	Juncaceae	black grass				U
Lonicera	*morrowii*	Caprifoliaceae	Morrow's				U
Oxalis	*stricta*	Oxalidaceae	common yellow				U
Paulownia	*tomentosa*	Paulowniaceae	princess tree				U
Persicaria	*perfoliata*	Polygonaceae	mile-a-minute				U
Phragmites	*australis*	Poaceae	common reed	L	LH	H	U
Phytolacca	*americana*	Phytolaccaceae	common pokeweed				U
Pluchea	*odorata*	Asteraceae	saltmarsh fleabane	L	LH	H	
Prunus	*serotina*	Rosaceae	black cherry				U
Rubus	*sp. NOT cut-*	Rosaceae	blackberry				U
Salicornia	*depressa*	Chenopodiaceae	common glasswort		LH	H	
Sambucus	*canadensis*	Caprifoliaceae	common elderberry				U
Scirpus	*sp.*	Cyperaceae	bulrush	L			
Solanum	*nigrum*	Solanaceae	European black				U
Solidago	*canadensis*	Asteraceae	Canada goldenrod				U
Solidago	*rugosa*	Asteraceae	wrinkle-leaf				U
Solidago	*sempervirens*	Asteraceae	seaside goldenrod	L	LH		U
Spartina	*alterniflora*	Poaceae	smooth cordgrass	L		H	
Spartina	*patens*	Poaceae	saltmeadow		LH	H	
Toxicodendron	*radicans*	Anacardiaceae	poison ivy				U

Table 5 Plant list for the Bellemead/Riverside sites: L - low, H - high, U - upland; and the transition areas: LH between low and high marsh, HU - between high marsh and upland.

Genus	**species**	**family**	**common name**	**LH**	**H**	**HU**	**U**
Ailanthus	*altissima*	Simaroubaceae	tree-of-heaven			HU	U
Ampelopsis	*brevipedunculata*	Vitaceae	porcelain-berry			HU	U
Atriplex	*prostrata*	Chenopodiaceae	thinleaf orach	LH		HU	U
Baccharis	*halimifolia*	Asteraceae	groundsel tree			HU	U
Calamagrostis	*cf. epigejos*	Poaceae	bushgrass				U
Dichanthelium	*clandestinum*	Poaceae	deer-tongue Witchgrass			HU	
Distichlis	*spicata*	Poaceae	saltgrass	LH	H	HU	U
Eleocharis	*parvula*	Cyperaceae	little-spike spikerush			HU	
Hibiscus	*moscheutos*	Malvaceae	swamp rose-mallow				U
Iva	*frutescens*	Asteraceae	maritime marsh elder	LH	H	HU	U
Juncus	*gerardii*	Juncaceae	black grass	LH	H	HU	U
Juncus	*tenuis*	Juncaceae	path rush			HU	
Lonicera	*morrowii*	Caprifoliaceae	Morrow's honeysuckle			HU	
Morella	*caroliniensis*	Myricaceae	small bayberry			HU	U
Morus	*alba*	Moraceae	white mulberry				U
Panicum	*virgatum*	Poaceae	switchgrass			HU	
Parthenocissus	*quinquefolia*	Vitaceae	Virginia creeper			HU	U
Phragmites	*australis*	Poaceae	common reed	LH	H	HU	U
Phytolacca	*americana*	Phytolaccaceae	common pokeweed			HU	U
Pluchea	*odorata*	Asteraceae	saltmarsh fleabane	LH			
Rhus	*copallinum*	Anacardiaceae	winged sumac			HU	
Rubus	*sp.*	Rosaceae	blackberry			HU	
Rumex	*crispus*	Polygonaceae	dock				U
Salicornia	*depressa*	Chenopodiaceae	common glasswort	LH			
Scutellaria	*sp.*	Lamiaceae	skullcap				U
Solidago	*rugosa*	Asteraceae	wrinkle-leaf goldenrod			HU	
Solidago	*sempervirens*	Asteraceae	seaside goldenrod	LH	H	HU	U
Spartina	*alterniflora*	Poaceae	smooth cordgrass	LH			
Spartina	*patens*	Poaceae	saltmeadow cordgrass	LH	H	HU	
Ulmus	*sp.*	Ulmaceae	elm				U

Table 6 Plant list for the Fish Creek Marsh site: L - low, H - high, U - upland; and the transition areas: LH between low and high marsh, HU - between high marsh and upland.

Genus	**species**	**family**	**common name**	**H**	**HU**	**U**
Acer	*saccharinum*	Aceraceae	silver maple			U
Ageratina	*altissima*	Asteraceae	common white			U
Alliaria	*petiolata*	Brassicaceae	garlic mustard		HU	
Asparagus	*officinalis*	Amaryllidaceae	garden asparagus			U
Asteraceae	*sp.*	Asteraceae				U
Atriplex	*prostrata*	Chenopodiaceae	thinleaf orach	H	HU	U
Baccharis	*halimifolia*	Asteraceae	groundsel tree	H	HU	U
Calamagrostis	*cf. epigejo*	Poaceae	Bushgrass		HU	U
Carex	*sp.*	Cyperaceae				U
Carex	*vulpinoidea*	Cyperaceae	common sedge		HU	U
Cirsium	*arvense*	Asteraceae	Canada thistle			U
Cirsium	*sp.*	Asteraceae	thistle		HU	
Distichlis	*spicata*	Poaceae	saltgrass	H	HU	U
Eleocharis	*parvula*	Cyperaceae	little-spike		HU	
Fraxinus	*pennsylvanica*	Oleaceae	green ash			U
Galium	*aparine*	Rubiaceae	cleavers bedstraw		HU	U
Hibiscus	*moscheutos*	Malvaceae	swamp rose-	H	HU	U
Iva	*frutescens*	Asteraceae	maritime marsh	H	HU	U
Juncus	*effusus*	Juncaceae	soft rush			U
Juncus	*gerardii*	Juncaceae	black grass	H	HU	U
Juncus	*tenuis*	Juncaceae	path rush		HU	
Juniperus	*virginiana*	Cupressaceae	eastern red cedar		HU	U
Lonicera	*morrowii*	Caprifoliaceae	Morrow's			U
Lythrum	*salicaria*	Lythraceae	purple loosestrife	H	HU	U
Melilotus	*albus*	Fabaceae	white sweetclover	H		
Morus	*alba*	Moraceae	white mulberry			U
Oxalis	*stricta*	Oxalidaceae	common yellow		HU	U
Parthenocissus	*quinquefolia*	Vitaceae	Virginia creeper		HU	U
Persicaria	*perfoliata*	Polygonaceae	mile-a-minute		HU	U
Phragmites	*australis*	Poaceae	common reed	H	HU	U
Phytolacca	*americana*	Phytolaccaceae	common		HU	U
Pluchea	*odorata*	Asteraceae	saltmarsh fleabane	H	HU	U
Poaceae	*sp.*	Poaceae			HU	
Polygonum or	*sp.*	Polygonaceae		H		
Rhus	*aromatica*	Anacardiaceae	fragrant sumac		HU	U
Rubus	*laciniatus*	Rosaceae	cut-leaved		HU	U
Rumex	*crispus*	Polygonaceae	curly dock		HU	U
Schedonorus	*pratensis*	Poaceae	meadow fescue			U
Solanum	*dulcamara*	Solanaceae	bittersweet		HU	U
Solidago	*canadensis*	Asteraceae	Canada goldenrod		HU	U
Solidago	*sempervirens*	Asteraceae	seaside goldenrod	H	HU	U
Sonchus	*oleraceus*	Asteraceae	sow-thistle			U

Genus	species	family	common name	H	HU	U
Spartina	*alterniflora*	Poaceae	smooth cordgrass	H		U
Spartina	*patens*	Poaceae	saltmeadow	H	HU	
Toxicodendron	*radicans*	Anacardiaceae	poison ivy		HU	U
Verbascum	*thapsus*	Scrophulariaceae	common mullein			U

Table 7 Plant list for the Harrier Meadow site: L - low, H - high, U - upland; and the transition areas: LH between low and high marsh, HU - between high marsh and upland.

Genus	species	family	common name	L	H	U
Acer	*negundo*	Aceraceae	box elder			U
Achillea	*millefolium*	Asteraceae	common yarrow			U
Agrostis	*sp.*	Poaceae	bentgrass			U
Ailanthus	*altissima*	Simaroubaceae	tree-of-heaven			U
Alliaria	*petiolata*	Brassicaceae	garlic mustard			U
Allium	*vineale*	Amaryllidaceae	field garlic			U
Amaranthus	*cannabinus*	Amaranthaceae	saltmarsh water-hemp	L		U
Ambrosia	*artemisiifolia*	Asteraceae	common ragweed			U
Ambrosia	*trifida*	Asteraceae	giant ragweed			U
Ampelopsis	*brevipedunculata*	Vitaceae	porcelain-berry			U
Artemisia	*vulgaris*	Asteraceae	mugwort			U
Asparagus	*officinalis*	Amaryllidaceae	garden asparagus			U
Atriplex	*prostrata*	Chenopodiaceae	thinleaf orach	L	H	U
Baccharis	*halimifolia*	Asteraceae	groundsel tree	L		U
Bromus	*japonicus*	Poaceae	Japanese chess			U
Calystegia	*sepium*	Convolvulaceae	hedge bindweed			U
Carex	*vulpinoidea*	Cyperaceae	common sedge			U
Daucus	*carota*	Apiaceae	Queen Anne's lace			U
Dipsacus	*fullonum*	Dipsacaceae	wild teasel			U
Distichlis	*spicata*	Poaceae	saltgrass	L	H	U
Festuca	*sp.*	Poaceae	fescue			U
Festuca	*sp.*	Poaceae	fescue			U
Hibiscus	*moscheutos*	Malvaceae	swamp rose-mallow			U
Iva	*frutescens*	Asteraceae	maritime marsh elder			U
Juncus	*gerardii*	Juncaceae	black grass			U
Juncus	*torreyi*	Juncaceae	Torrey's rush			U
Lonicera	*japonica*	Caprifoliaceae	Japanese honeysuckle			U
Lonicera	*morrowii*	Caprifoliaceae	Morrow's honeysuckle			U
Lythrum	*salicaria*	Lythraceae	purple loosestrife			U
Melilotus	*albus*	Fabaceae	white sweetclover			U
Oxalis	*stricta*	Oxalidaceae	common yellow wood-			U
Parthenocissus	*quinquefolia*	Vitaceae	Virginia creeper			U
Phragmites	*australis*	Poaceae	common reed	L	H	U
Pluchea	*odorata*	Asteraceae	saltmarsh fleabane	L	H	
Poa	*sp.*	Poaceae	bluegrass			U
Poaceae	*sp.*	Poaceae				U
Poaceae	*sp.*	Poaceae				U
Poaceae	*sp.*	Poaceae				U
Poaceae	*sp.*	Poaceae				U
Poaceae	*sp.*	Poaceae				U
Rhus	*copallinum*	Anacardiaceae	winged sumac			U

Genus	species	family	common name	L	H	U
Robinia	*pseudoacacia*	Fabaceae	black locust			U
Rosa	*multiflora*	Rosaceae	multiflora rose			U
Rubus	*sp. NOT cut-leaved*	Rosaceae	blackberry			U
Rumex	*crispus*	Polygonaceae	curly dock			U
Scirpus	*sp.*	Cyperaceae	bulrush	L		U
Solanum	*dulcamara*	Solanaceae	bittersweet nightshade			U
Solidago	*canadensis*	Asteraceae	Canada goldenrod			U
Solidago	*sempervirens*	Asteraceae	seaside goldenrod	L	H	U
Spartina	*alterniflora*	Poaceae	smooth cordgrass	L		U
Spartina	*patens*	Poaceae	saltmeadow cordgrass	L	H	U
Toxicodendron	*radicans*	Anacardiaceae	poison ivy			U
Verbascum	*thapsus*	Scrophulariaceae	common mullein			U

Table 8 Plant list for the Hawk Property site: L - low, H - high, U - upland; and the transition areas: LH between low and high marsh, HU - between high marsh and upland.

Genus	**species**	**family**	**common name**	**L**	**LH**	**H**
Atriplex	*prostrata*	Chenopodiaceae	thinleaf orach	L	LH	
Salicornia	*depressa*	Chenopodiaceae	common glasswort	L	LH	
Eleocharis	*parvula*	Cyperaceae	little-spike spikerush	L	LH	
Juncus	*gerardii*	Juncaceae	black grass			H
Distichlis	*spicata*	Poaceae	saltgrass	L	LH	H
Phragmites	*australis*	Poaceae	common reed	L	LH	H
Spartina	*alterniflora*	Poaceae	smooth cordgrass	L	LH	H
Spartina	*patens*	Poaceae	saltmeadow cordgrass		LH	H

Table 9 Plant list for the Riverbend site: L - low, H - high, U - upland; and the transition areas: LH between low and high marsh, HU - between high marsh and upland.

Genus	species	family	common name	L	LH	H
Amaranthus	*cannabinus*	Amaranthaceae	saltmarsh water-hemp	L	LH	H
Atriplex	*prostrata*	Chenopodiaceae	thinleaf orach	L	LH	H
Distichlis	*spicata*	Poaceae	saltgrass		LH	H
Eleocharis	*parvula*	Cyperaceae	little-spike spikerush	L		
Juncus	*gerardii*	Juncaceae	black grass		LH	H
Persicaria	*cf. lapathifolia*	Polygonaceae	pale smartweed			H
Phragmites	*australis*	Poaceae	common reed	L	LH	H
Pluchea	*odorata*	Asteraceae	saltmarsh fleabane			H
Rumex	*crispus*	Polygonaceae	curly dock			H
Scirpus	*sp.*	Cyperaceae	bulrush	L	LH	H
Solidago	*sempervirens*	Asteraceae	seaside goldenrod	L	LH	H
Spartina	*alterniflora*	Poaceae	smooth cordgrass	L	LH	H
Spartina	*cynosuroides*	Poaceae	giant cordgrass		LH	H
Spartina	*patens*	Poaceae	saltmeadow cordgrass		LH	H
Typha	*latifolia*	Typhaceae	broadleaf cattail			H

Table 10 Plant list for the Secaucus High School Marsh site: L - low, H - high, U - upland; and the transition areas: LH between low and high marsh, HU - between high marsh and upland.

1.4.1.1 Diversity pattern

Small-scale plant richness (1 m^2) increased fairly linearly along transects from low marsh to upland (Figure 13). Both large-scale plant-richness (100 m^2, Figure 14) and beta-diversity pattern (Figure 15) increased in a single step up from the species poor marsh habitats to the relatively species rich upland.

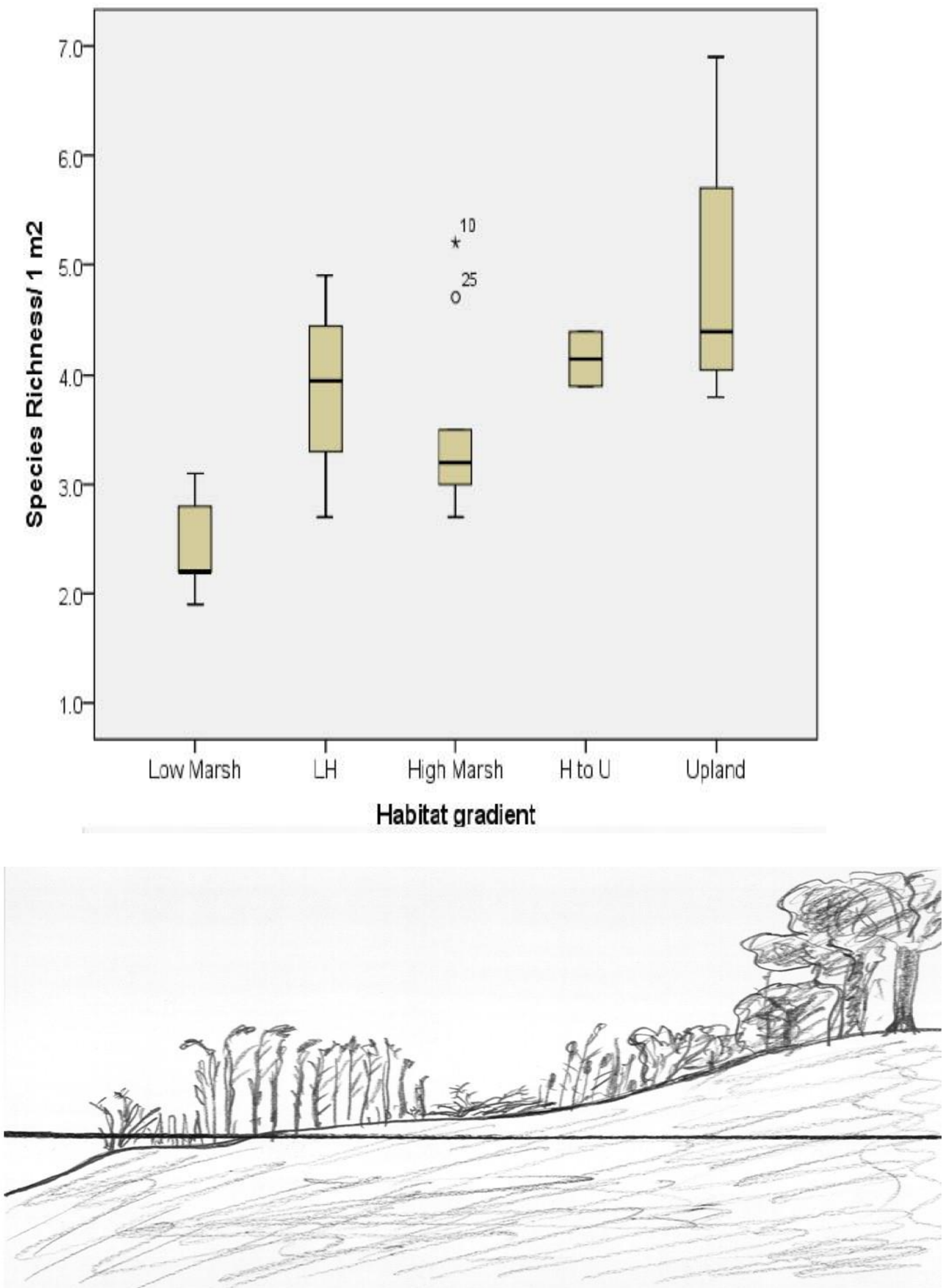


Figure 13 Boxplot of small-scale richness (species per 1 m^2) along habitat gradient

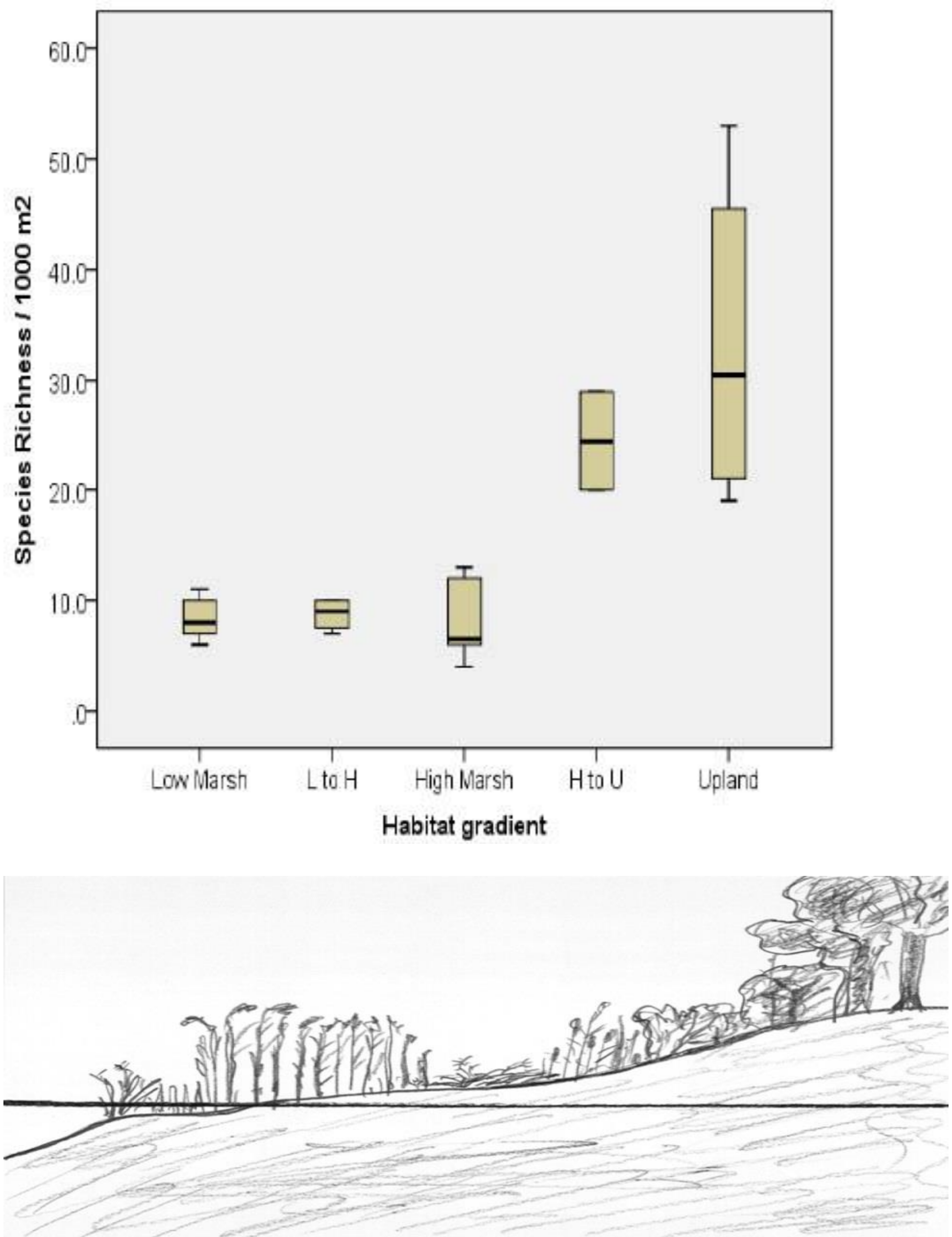


Figure 14 Boxplot of large-scale richness (species per 1,000 m^2) along habitat gradient

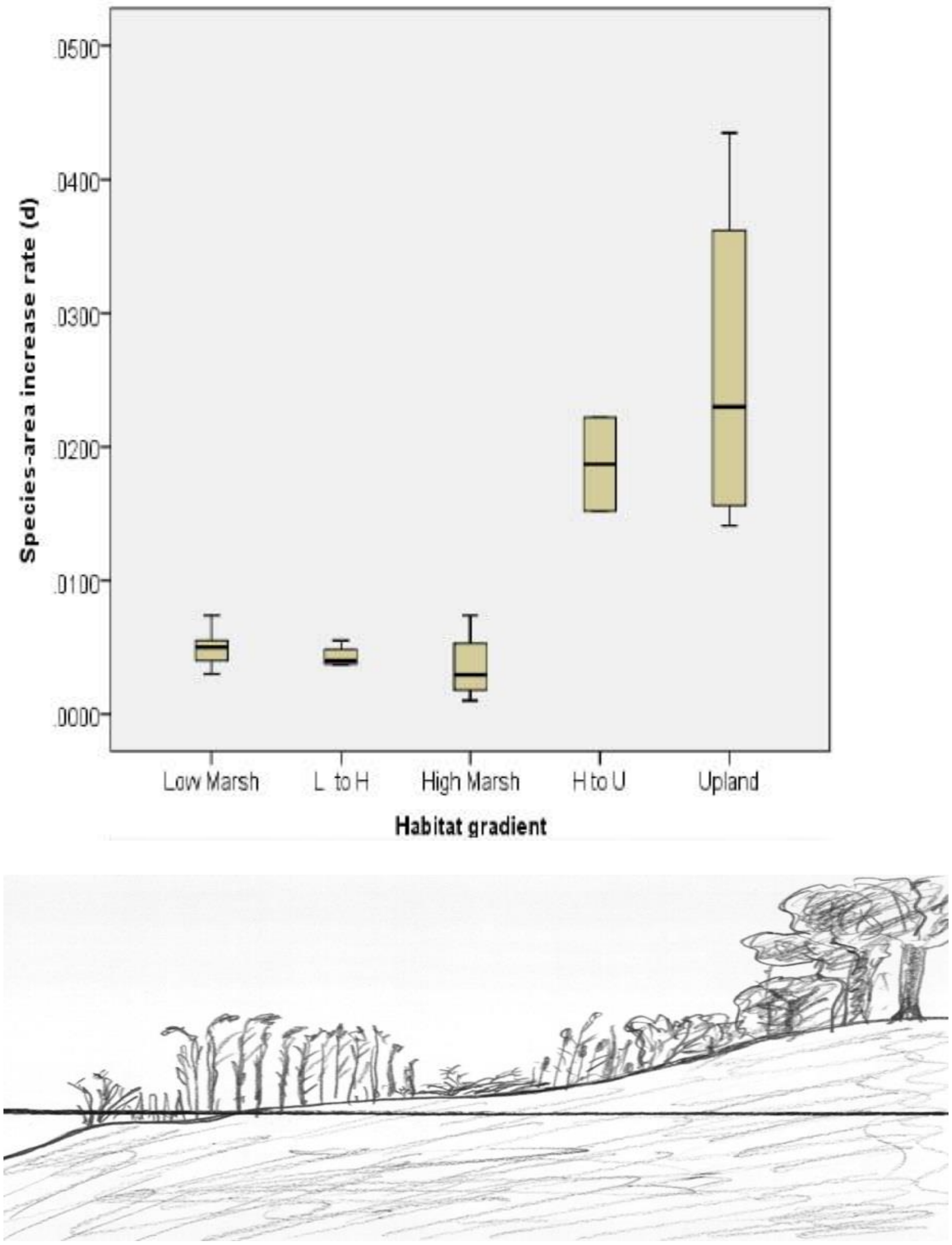


Figure 15 Boxplot of d, the rate of increase in richness when enlarging plots, along habitat gradient

1.4.1.2 Community composition patterns

Canonical Correspondence Analysis confirms that the gradient in species richness is correlated to the elevation gradient and shows a vegetation cover (and Leaf Area Index) gradient perpendicular to it as shown in Figures 13, 14 and 15. This demonstrates that plant cover and Leaf Area Index (LAI), both correlates of productivity, are not directly correlated to the richness gradient. The highest values of these productivity correlates are found in the high marsh, but all habitats varied widely in cover and LAI as demonstrated by the spread along axis 2. This is more prominent for the low and high marsh than the upland. Figure 11 indicates which species are typical for which habitats, and the emerging pattern is not surprising. *Spartina alterniflora* is associated with the low marsh*, Spartina patens* with the high marsh, and a number of upland grasses, forbs and shrubs with the upland habitat. Interesting is the association of the invasive *Phragmites australis* with the center of the ordination space, which indicates the relative even distribution of that species along the habitat transect which does not allow one to discern a particular habitat specialization of this ubiquitous invader, shown also in Figure 16.

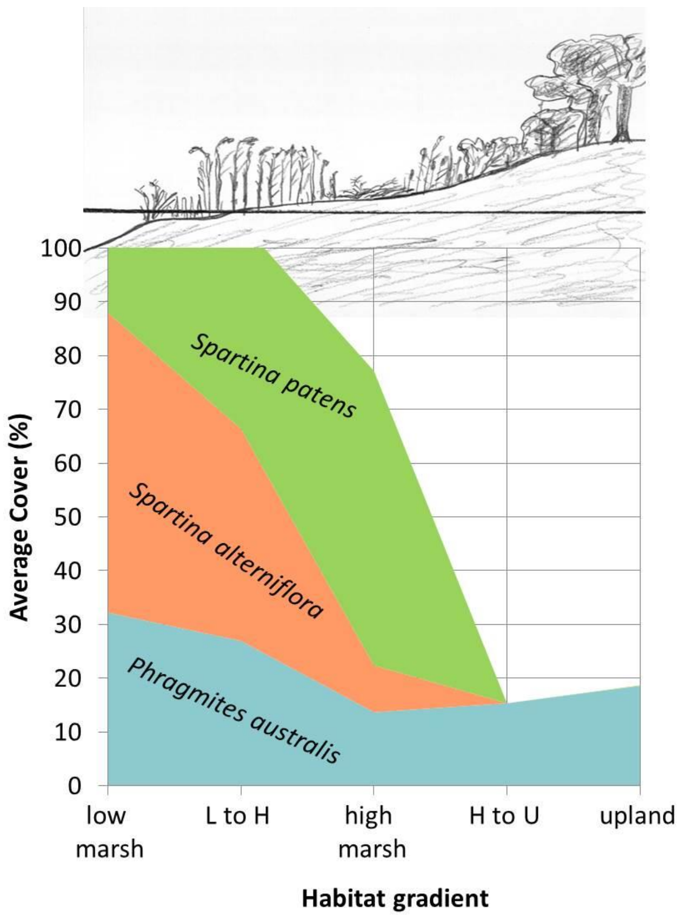


Figure 16 Average contribution (in cover percent) of the three dominant marsh grasses *Spartina patens*, *S. alterniflora* (both native) and *Phragmites australis* (introduced) along the habitat gradient. Data are based on 1 m^2 plots within Whittaker plots.

1.4.2. Conservation values

More than half of the plants that were listed in this survey had the lowest C C values (0-3), and made up the largest group of species identified. More than half of those "0-3" species in the list are scored as 0. Of the species that scored a 0, several are on the NJ Invasive Species Strike Team 2015 Invasive Species List (http://www.njisst.org/resources.htm) and the New Jersey Strategic Management Plan for Invasive Species (New Jersey Invasive Species Council, 2009) including: *Ailanthus altissima* (tree-of-heaven), *Alliaria petiolata* (garlic mustard), *Ampelopsis brevipedunculata* (porcelain vine), *Artemisia vulgaris* (mugwort), *Cirsium arvense* (Canada thistle), *Lonicera japonica* (Japanese honeysuckle), *Lonicera morrowii* (Morrow's honeysuckle), *Lythrum salicaria* (purple loosestrife), *Phragmites australis* (common reed), *Persicaria perfoliata* (mile-a-minute), *Rosa multiflora* (multiflora rose), *Robina pseudoacacia* (black locust) and *Rubus laciniatus*, (cut-leaved blackberry). These plants are listed as problematic species because they may threaten the health of the natural ecosystem by impacting native plants and animals. The New Jersey Strategic Management Plan for Invasive Species (New Jersey Invasive Species Council (2009) also lists *Allium vineale*, *Asparagus officinalis*, and *Calamagrostis epigeios*, which are found at this study's sites.

P. australis has a coefficient of 0 and is a common plant found at all of the sites surveyed. The common reed is widely distributed throughout the rest of the Meadowlands and grows as a dominant plant forming dense monocultures of vegetation at many sites. This is a condition of the many disturbed and degraded areas that can be found in the District.

The species that were assigned a coefficient of 1, 2, or 3 are also defined as plants with a high range of ecological tolerances found in a variety of plant communities. These species were found at many of the site. There was no single plant with a coefficient of 1, 2, or 3 which was found at all of the surveyed sites.

Although, *Solidago sempervirens* has a coefficient of 2, is not invasive, and was found at every site except Riverbend. *S. sempervirens* grows in a mixture of vegetation and can also be found throughout the rest of the District.

The species that were assigned coefficients of 4, 5, or 6 are defined as plants with an intermediate range of ecological tolerances. The species that have coefficients in this range and can be found at all of the sites surveyed are *Atriplex prostrata* (halberd-leaved orach) coefficient of 5, *Spartina alterniflora* (salt marsh cordgrass) coefficient of 6 and *Spartina patens* (saltmeadow cordgrass) coefficient of 5. *S. alterniflora* is the only species of this group that grows throughout the Meadowlands in either dense clusters or as a dominant plant. The *A. prostrata* and *S. patens* grow as a mixture with other plants.

Pluchea odorata, coefficient 5 and *Hibiscus moscheutos*, coefficient 5, were found growing at most of the survey sites and are also commonly found in other places throughout the District. A stand of *Myrica pennsylvanica* shrubs has a coefficient of 4 are only growing at Fish Creek Marsh. *Salicornia depressa* has a coefficient of 4 and can be found growing as the dominant plant in areas of mud at Riverbend. *S. depressa* is also found at the other locations but growing in small clusters of plants or only a few single plants.

Species assigned a coefficient of 7 are defined as having a narrow range of ecological tolerances were *Amaranthus cannabinus* (salt-marsh water-hem) and *Spartina cynosuroides* (big cordgrass). There were no species identified in the survey that shared this definition with a coefficient of 8.

Amaranthus cannibinus can be found growing as a few plants at half the survey sites; Hawk Property, Riverside/Bellemead and Secaucus High School. *Spartina cynosuroides* was only found growing at Secaucus High School marsh in dense clusters or as a mixture of vegetation. There are few other places in the District where S*. cynosuroides* can be found growing as either a few single plants or smaller dense stands. The only other known location where it grows as a viable population of plants is the Marsh Resources Mitigation Bank Phase 1, Carlstadt, NJ.

The species identified and assigned a coefficient of 9 and 10 are defined as plants with a high degree of fidelity to a narrow range of pristine habitats. This group had the least amount of species identified in the survey. *Distichlis spicata* (saltgrass) and *Eleocharis parvula* (little-spike spikerush) both assigned a coefficient of 9 and *Scutellaria nervosa* (small skullcap) coefficient 10. *Distichlis spicata* can be found at all of the survey sites; growing in either dense mats or as a mixture with *S. patens*. *Distichlis spicata* is limited to these high marsh areas, but not found in many other places in the District. *Eleocharis parvula* can be found at all of the survey sites and growing throughout the Meadowlands in high marsh, low marsh or on the mudflats. *Scutellaria nervosa*, was found at only one survey location at Fish Creek and has not been identified anywhere else in the District. It is a species of concern and ranked (S2) imperiled in New Jersey.

Section II – Topography and site hydrology

2.1 Introduction

A sustainable marsh can be defined as being in a dynamic equilibrium with its environmental factors (Mitsch and Gosselink, 2000). The state of equilibrium of a micro-tidal coastal wetland is a result of many factors including its hydroperiod, sediment availability, sediment settling velocity, and above and below ground plant productivity (Allen, 2000). Each flooding tide introduces to a site and channel system a certain volume of water or tidal prism. Depending on the tide, this prism can be *undermarsh* when it is contained within the channel system, *bankfull* when it reaches the banks of the creek system or *overmarsh* tidal prism when water overtops the creek banks and floods the marsh platform. The height difference between the marsh platform and the high water is called hydraulic duty (Allen, 1994). *Hydraulic duty* is a height difference but can also be defined as a quotient between tidal prism (m^3) and catchment area (m^2) in which case is called unit tidal prism and is like a conventional measure of rainfall. The concept of unit tidal prism can be used in several ways as an integrative measure of hydrological impairment since sedimentation rates depend on the pattern and extent of tidal inundation (Hartnoll and Hawkins, 1982). According to Alan (2000), a youthful marsh platform may be submerged by about half of the tides in an average year whereas a mature one may be drowned on just a few tens of occasions. In this case we use the area that remains free of inundation at mean high water (approximately 2.5ft NAVD88) as a measure of impairment to sea level rise. The remaining area above the intertidal zone can be used to accommodate marsh retreat due to variations in relative sea level rise (Morris et al., 2002). The more area not inundated by mean high water, the more space available for the marsh to expand under conditions of sea level rise. Stage velocity curves (French and Stoddart, 1992), may have a peak as the creek starts to fill or finally empty depending on the observation point. Usually there is a significant increase in channel water velocity as water levels overcome the banks of creeks and the huge storage capacity of the marsh platform comes into play (Allen, 2000). As water level overcomes its banks the area inundated becomes greater, therefor discharge increases in response to this demand (Fagherazzi et al., 2013). Typically, the ebb flow in a channel is stronger and peaks at a lower stage than the flood (Stoddart et al., 1987) but this pattern changes depending if the observation point is close to the head of the catchment or to the sea ward end (Healey et al., 1981). A meaningful impairment metrics is obtained by analyzing stage velocity curves at similar observation points in different sites and for similar lengths of time. The metric is based on comparisons between periods of low velocity where suspended sediments would settle and periods of high velocities that would cause erosion and the asymmetries between these two. Another useful concept in wetland hydrology is the *renewal rate* or *turnover rate* defined as the ratio of throughput to average volume of the system (Mitsch and Gosselink, 2000). This measures how rapidly water in the system is replaced and the inverse is an indication of how long water remains in a given system or its residence time and is based on the geomorphology of a marsh. An important function of natural wetlands is the breakdown of organics matter and releasing nutrients into the estuary. The greater the residence time the less effective wetlands are in pumping organic matter and nutrients into the estuary. On the other hand, fine sediment suspended in the water column is more likely to not settle and be removed from a marsh given a low residence time (Fagherazzi et al., 2013). From an urban estuary perspective where loads of dissolved inorganic nitrogen are high, greater residence times are more desirable, as it would allow for nitrogen to drop out of the water column and be retained by marsh sediments from where it can undergo denitrification. Bayliss-Smith et al. (1979) and French and Stoddart (1992) believe that under normal tide conditions creeks exist in dynamic equilibrium and that sedimentation and erosion episodes over the long run effectively cancel each other out. In the absence of exceptional conditions (i.e. storm surges, earthquakes etc.) there should not be excessive sedimentation in creeks or unusual widening of tidal creeks due to scouring and erosion. Measuring and mapping the bathymetry of tidal creeks can be an important metric that signals unexpected or excessive siltation and/or widening of creeks by erosion due to external factors upsetting the natural dynamic creek equilibrium (e.g. wetland filling or construction). In this section, continuous stage measurements along with the analysis of stage velocity curves over multiple tidal cycles, wetland topography and channel bathymetry are combined into a series of hydrological impairment metrics that help characterize each one of the creeks involved in the study.

The study sites selected for the hydraulic study are Bellemead Mitigation, Fish Creek Marsh, Hawk Property, Lyndhurst Riverside Marsh, Riverbend Wetlands Preserve, Secaucus High School Marsh, and a supplemental site Anderson Creek. Harrier Meadow was omitted from the hydraulic study due to its lack of natural hydraulic connectivity.

Bathymetry data collection at Bellemead Ditch July, 2014. Photo by F. Artigas

2.2 Methods

2.2.1 LiDAR Acquisition

Accurate elevation measurements of marsh surfaces were required to measure inundation levels, area and water volumes to calculate hydrological impairment metrics such as hydraulic duty, residence time and unit tidal prism. In February 2014, Quantum Spatial, Inc. (QSI) was contracted to collect Light Detection and Ranging (LiDAR) data of the Hackensack Meadowlands District for the spring of 2014. This was accomplished using a Leica ALS50 phase II system mounted in a Cessna Caravan. Table 11 summarizes the settings used to yield an average pulse density of >8.0 pulses/m2 (0.74 pulses/ft2) over the project area.

Acquisition Dates	April 10 - 11, 2014
Aircraft Used	Cessna Caravan
Sensor	Leica ALS50 Phase II
Survey Altitude (AGL)	1500 m
Target Pulse Rate	105 kHz
Pulse Mode	Multiple Pulse in Air (MPiA)
Laser Pulse Diameter	34 cm
Field of View	24°
GPS Baselines	≤13 nm
GPS PDOP	≤3.0
GPS Satellite Constellation	≥6
Maximum Returns	4
Intensity	8-bit
Resolution/Density	Average 8 pulses/m2
Accuracy	RMSEZ ≤ 15 cm

Table 11 Lidar Survey settings and specifications

LiDAR data (2014) was used to create digital elevation model (DEM) for each study area that in turn were used to create the inundation hypsography for each site. The DEM was imported into ENVI software in order to calculate area percentages at each incremental foot from -2 ft to 9.99 ft (NAVD88). ENVI did so using the compute statistics tool; this created a histogram with pixel intensity for each elevation range. The data was then exported to a table to generate the hypsography for each site. Hydraulic connectivity was created by digitizing stream centerlines and the centerlines were burnt into the DEM. Inundation maps were created for each study area using ArcMap and the study areas corresponding DEM. The maps display water elevation at 2.5 ft NAVD88.

2.2.2 Stage Velocity Curves and Tidal Asymmetry

Stage velocity curves were created to visualize tidal cycles periods of low velocity where suspended sediments would settle and periods of high velocities that would cause erosion. Stage and water velocity were measured simultaneously within each site (total of seven sites) but at different times periods between July 8, 2014 and September 18, 2014. The sensors cluster (Figure 17) consisted of a CS451-L pressure transducer, Sontek Argonaut 3 beam down-looking ADV, and YSI 6600 Multi-parameter Sonde. Tidal creek bottom elevations were collected using an echo sounder sonar and banks were surveyed using a Trimble Rover GPS 5700. At each creek, measurements were recorded for 14 to 28 continuous tidal cycles at 15 minute intervals using a Campbell Scientific CR800 data logger. Data was retrieved as a comma limited (CSV) file and stage measurements converted to NADV88 datum using surveyed information from each sampling station. Velocity measurements from the Argonaut ADV sensor were calculated as the combined vector (velocity magnitude) of the x and y axis measurements. Positive and negative values were applied to velocity measurements to indicate flood or ebb cycles based on stage measurements. Stage velocity curves were graphed to visualize tidal asymmetries. Average flood and ebb velocities were plotted against stage ranges in order to identify elevations where these asymmetries were greater.

Figure 17 Sensor cluster from left to right: Sontek Argonaut 3 beam down looking ADV, CS451-L pressure transducer, YSI 6600 Multi-parameter Sonde

2.2.3 Bathymetry

A Lowrance HDS-5 Gen2 echo sounder Sonar and GPS was used to create bathymetric raster images of the seven tidal creeks that were later used to calculate cross sections. The sonar transducer was fixed to the end of a Trimble 5700 survey pole collecting RTK vertical elevations in NAVD88 Geoid12a. Elevations were taken at the beginning and end of each survey in order to tie in depth data to a vertical coordinate system and account for any tidal fluctuations. It should be noted that measurements on pitch, roll and yaw of the boat were not accounted for. The transducer and survey pole were mounted onto a boat that surveyed the left, right, and center side of the creek for the total length of the creek. Boat speed did not exceed 3 mph. The sonar unit recorded water depth as well as GPS location.

The sonar used an active transducer operating at 200 kHz with a 10 degree beam width. Water depth and positional data was recorded and saved onto a flash drive as a CSV. In order to calculate river bottom elevation we subtracted the water depth from the transducer elevation in NAVD88. Any differences in tidal fluctuation were also factored into the dataset. Outliers were identified using an interquartile range analysis and the resulting data was mapped using the positional information recorded during the survey in an ArcGIS/ArcMAP environment. The resulting data was merged with surface contour data and then interpolated into a DEM using kriging techniques in ArcGIS.

2.2.4 Water Residence Time

In wetland hydrology the renewal rate or turnover rate is defined as the ratio of throughput to average volume of the system. The inverse of renewal time is water residence time which can be used as a metric for organic matter output by wetlands to the estuary. The renewal rate indicates how rapidly the water in the system is replaced. The reciprocal is the residence time which is a measure of the average time that water remains in the wetland (Mitsch, 2000).

t^{-1} = renewal rate (time $^{-1}$)
Q_t = total inflow rate (volume/time)
V = average volume of water storage in the wetland

$$t^{-1} = \frac{Q_t}{V}$$

The inflow rate (discharge) was calculated using data from the velocity sensor and cross-sectional area. Wetland water storage was calculated by deriving the total volume under the average stage elevation for each site using the DEM.

2.3 Results

2.3.1 Hydraulic Duty

Hydraulic duty results for each site are presented in Table 12. Anderson, Secaucus, and Riverbend exceed all other sites by a level of magnitude indicating that these three sites are able to hold greater volumes of water at mean high water in less amount of area compared to the other sites. Bellemead on the other hand, showed the lowest hydraulic duty height indicating that at mean high water it holds the least amount of water in relation to its area.

Site	Catchment Area (m^2)	Volume under 2.5ft NAVD88 (m^3)	Hydraulic Duty (m)
Anderson	66837.74	40570.51	0.61
Bellemead	25881.40	2026.44	0.08
Fish Creek	67820.40	1793.65	0.03
Hawk Prop.	42379.10	3125.27	0.07
Lynd. Riverside	60259.70	3932.63	0.07
Riverbend	206640.00	21500.25	0.10
Secaucus	135592.00	27723.01	0.20

Table 12 Hydraulic duty (tidal unit prism) in meters for each site

2.3.2 Inundation and Hypsography

Inundation hypsography shows potential areas at each site that could accommodate low marsh communities under conditions of sea level rise. Table 13 shows the percent of area of each site for the different elevation intervals. We selected Mean High Water (2.9 feet NADV88) as a level that occurs daily at these sites. Under present conditions Bellemead and Hawk show the greatest percent of area available for inundation under future sea level rise scenarios (79.4 and 61.8 % respectively). Fish Creek and Riverside are intermediate (56.0 and 50.0 %), while Riverbend and Secaucus have the least available areas for expansion (28.1 and 18.8 %). Inundation was also mapped for each site using a DEM queried for elevations below 2.5 feet NAVD88, see Figures 18-24.

Elev. Range (NAVD88 ft)	Bellemead Mitigation	Fish Creek	Hawk Property	Lyndhurst Riverside	Riverbend	Secaucus High School
-1	0.74%	10.82%	4.07%	2.77%	3.75%	0.02%
-1	0.79%	1.65%	5.59%	2.15%	2.79%	2.48%
0 - 0.9	5.16%	5.19%	8.45%	7.26%	7.08%	12.21%
1 - 1.9	13.87%	4.19%	5.04%	4.61%	10.74%	30.78%
2 - 2.9	38.44%	22.07%	14.96%	32.78%	47.47%	35.71%
3 - 3.9	19.85%	48.97%	32.45%	48.99%	24.45%	14.78%
4 - 4.9	9.59%	5.99%	7.82%	0.50%	1.40%	2.27%
5 - 5.9	4.15%	1.10%	5.58%	0.28%	0.98%	0.67%
6 - 6.9	4.35%	0.01%	7.49%	0.13%	0.52%	0.32%
7 - 7.9	2.19%	0.00%	4.51%	0.29%	0.16%	0.37%
8 - 8.9	0.73%	0.00%	2.27%	0.21%	0.12%	0.36%
9 - 9.9	0.13%	0.00%	1.07%	0.03%	0.11%	0.03%
10 - 10.9	0.00%	0.00%	0.48%	0.00%	0.12%	0.00%
11 - 11.9	0.00%	0.00%	0.18%	0.00%	0.17%	0.00%
12 - 12.9	0.00%	0.00%	0.03%	0.00%	0.11%	0.00%
13 - 13.9	0.00%	0.00%	0.01%	0.00%	0.04%	0.00%
14 - 14.9	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 13 shows percent of area belonging to each elevation range

Figure 18 Anderson Creek inundation at 2.5 ft

Figure 19 Bellemead Mitigation inundation at 2.5 ft

Figure 20 Fish Creek Marsh inundation at 2.5 ft

Figure 21 Hawk Property inundation at 2.5 ft

Figure 22 Lyndhurst Riverside inundation at 2.5 ft

Figure 23 Riverbend Wetland Preserve inundation at 2.5 ft

Figure 24 Secaucus High School Marsh inundation at 2.5 ft

2.3.3 Stage Velocity Curves and Tidal Asymmetry

Stage velocity curves were measured between July 8, 2014, and September 18, 2014. Each creek was measured separately so exact comparisons among creeks are not possible because each one was measured under a slightly different set of tidal conditions. The flood and ebb velocities for all creeks at different stages and for several tidal cycles are shown in Table 14. In creeks where stage exceeded the banks (overmarsh prism, Figure 25-28) a peak in flood velocity was observed as the marsh platform came into play and the ebb flow peaked slightly higher and in many cases at a lower stage than the flood. Studies show that flood dominance is usually observed at sampling points close to the head of the catchment while ebb dominance is observed in the middle reaches and flood and ebb velocities are balanced at the seaward end (Stoddart et al., 1987). In our case, stations were located between the seaward end and the middle reach of creeks and overall ebb velocities were higher (Table 14). Intuitively, the higher ebb velocities observed at these locations should indicate greater erosion during the ebb cycle. However along the entire creek and because of the different asymmetries there seems to be a dynamic equilibrium in sedimentation where over time siltation and erosion cancel each other out. This dynamic equilibrium is confirmed by observations and measurements in the field indicating overall low siltation and erosion in creeks. When turbidity measurements (a surrogate for suspended solids in the water column) are simultaneously measured with stage velocity, turbidity is consistently higher during the flood cycle (Artigas 2015, personal communication). This may help explain an average 6.5 mm/yr accretion rate experienced by these wetlands (MERI, 2014). The stage velocity curve pattern observed in this study (Figure 25-28) are in agreement with stage velocity curves measured elsewhere (Pethick, 1980, Healy et al., 1981, Stoddart et al., 1987, French and Stoddart, 1992, Reed et al., 1985, Pringle 1995). Bellemead Creek (Figure 30) showed a different pattern where flood velocity was always higher than the ebb velocity. In the cases of Fish Creek (Figure 31) and Riverbend (Figure 29), the tidal prism never reached overmarsh levels so the marsh platform effect never came into play.

Low flow velocities at undermarsh stages and around the high water slack should allow for suspended solids to settle on creek beds and marsh platforms. We expect that creeks that have similar flood and ebb velocities (less asymmetry) to be more at equilibrium compared to ones that have greater differences between flood and ebb. Impairment metric based on asymmetry of flood and ebb velocity (asymmetry Index) was calculated as the averaged difference from the selected stage range from the quotients of the flood/ebb and ebb/flood within each site. The selected stage range was between 0.5 and 3.5 feet NAVD88 for each creek, this is a stage range which every site shared. An asymmetry index of 0 would indicate equal flood and ebb velocities. SHS, Mary Ann Creek and RB had asymmetry index values closer to 0 (0.7, 0.8 and 1.1 respectively). HP and FC had intermediate values (1.5 and 2.1 respectively) while BD and AC had the greatest asymmetries (2.5 and 2.6 respectively).

Stage Range (NAVD88)	Anderson Creek		Bellemead Ditch		Fish Creek		Hawk Property		Mary Ann Creek		Riverbend Preserve		Secaucus HS	
	Ebb V	Flood V	Ebb V	Flood V	Ebb V	Flood V	Ebb V	Flood V	Ebb V	Flood V	Ebb V	Flood V	Ebb V	Flood V
-3.00 2.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.49	0.77	0.00	0.00
-2.50 2.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.69	2.06	1.61	2.16
-2.00 1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.63	2.31	2.00	2.09
-1.50 1.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.39	3.72	2.68	1.86
-1.00 -0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.32	4.63	3.60	3.04
-0.50 0.01	0.00	0.00	0.00	0.00	0.00	0.00	5.92	7.61	0.00	0.00	3.15	4.52	4.92	4.03
0.00 0.49	0.00	0.00	2.95	0.00	0.00	0.00	3.89	6.45	0.00	0.00	5.22	5.17	7.16	5.80
0.50 0.99	12.00	4.27	3.46	6.75	2.08	1.36	2.94	6.98	11.65	6.67	4.47	6.46	10.81	8.10
1.00 1.49	16.46	3.74	3.00	6.27	1.38	8.81	2.09	6.25	10.57	9.95	4.44	5.50	17.42	9.76
1.50 1.99	20.59	5.09	4.24	10.34	0.94	2.22	2.66	5.95	11.81	10.33	3.94	7.01	16.62	12.92
2.00 2.49	22.53	5.74	3.94	11.12	1.70	4.74	5.88	6.34	10.86	8.12	3.47	8.51	14.14	14.81
2.50 -2.99	14.16	10.66	3.52	7.86	3.51	3.94	6.99	11.05	16.43	9.03	4.71	8.30	10.24	14.18
3.00 3.49	9.50	5.93	2.02	12.12	3.08	4.66	7.09	14.03	29.96	17.19	19.58	11.23	6.89	11.99
3.50 3.99	4.34	4.71	4.29	8.63	0.00	0.00	4.78	10.17	29.49	18.82	0.00	0.00	2.75	7.92
4.00 4.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.78	7.49	0.00	0.00	0.00	0.00
5.00 5.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 14 Flood and ebb velocities (cm/s) by stage (feet). Velocity is colored from low (green) to high (red).

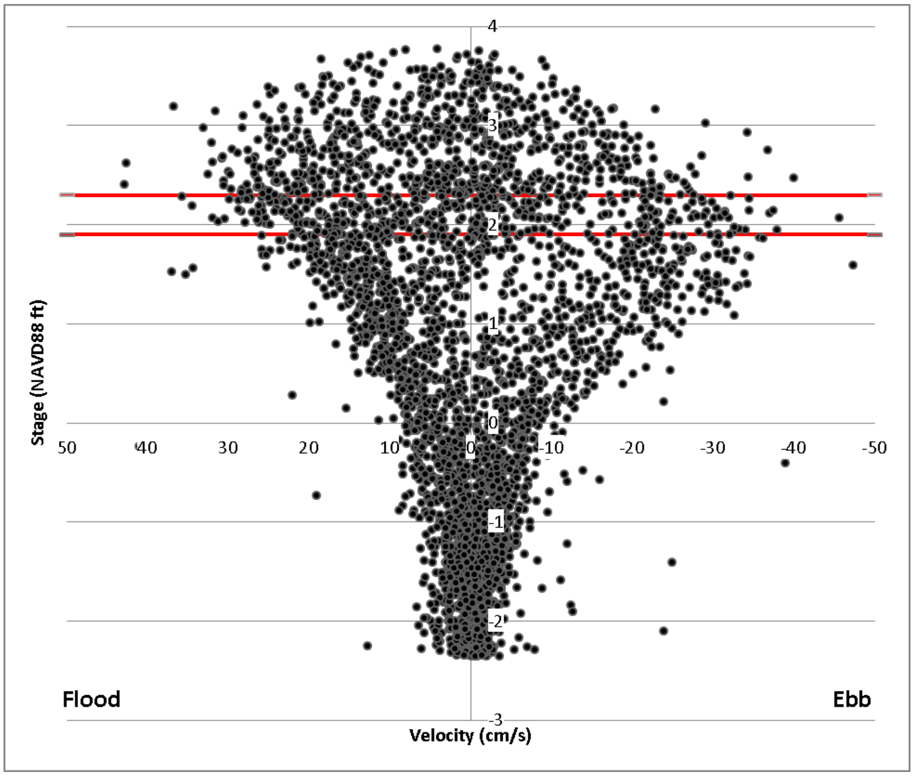


Figure 25 Secaucus High School Marsh: Sampled from 10/8/2014 – 11/5/2014, bank elevation: left 2.3 ft, right 1.9 ft. Peak flood velocity is seen above bankfull, peak ebb velocity occurs at bank.

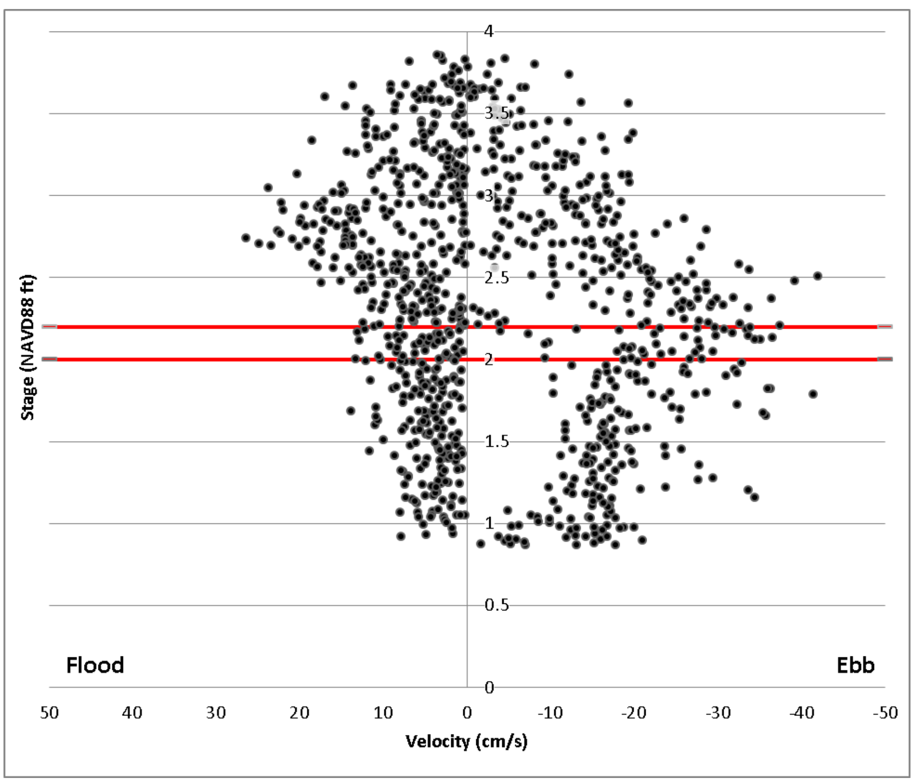


Figure 26 Anderson Creek: Sampled from 9/24/2014 – 10/8/2014, bank elevation: left 2.2 ft, right 2.0 ft. Peak flood velocity is seen above bankfull, peak ebb occurs at bank.

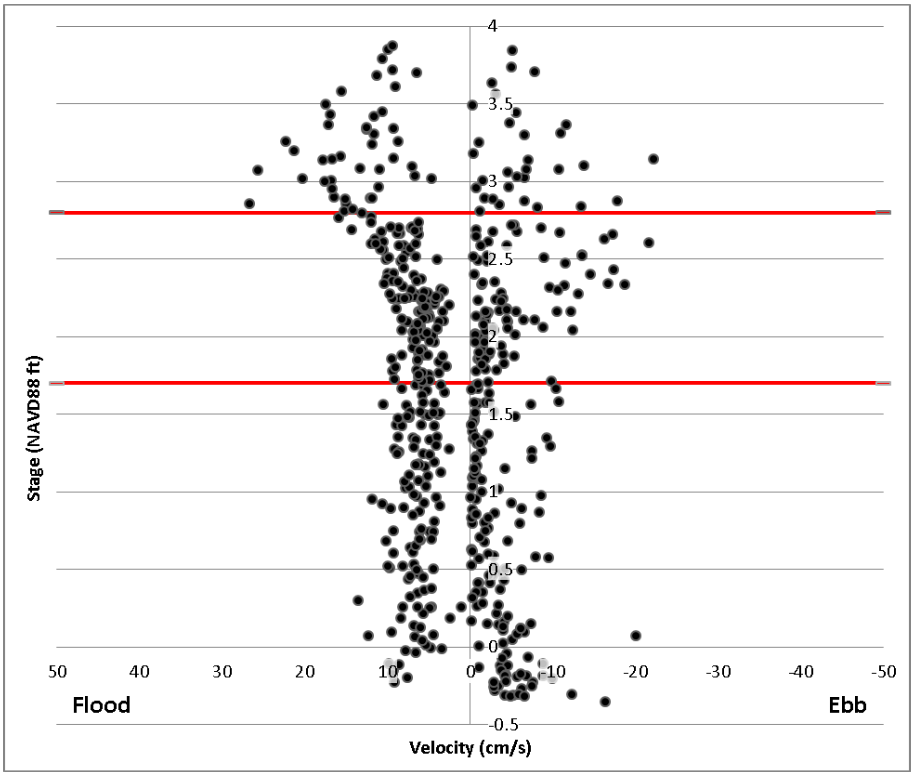


Figure 27 Hawk Property: Sampled from 8/1/2014 – 8/11/2014, bank elevation: left 1.7 ft, right 2.8 ft. Flood velocity dominant after overmarsh flow.

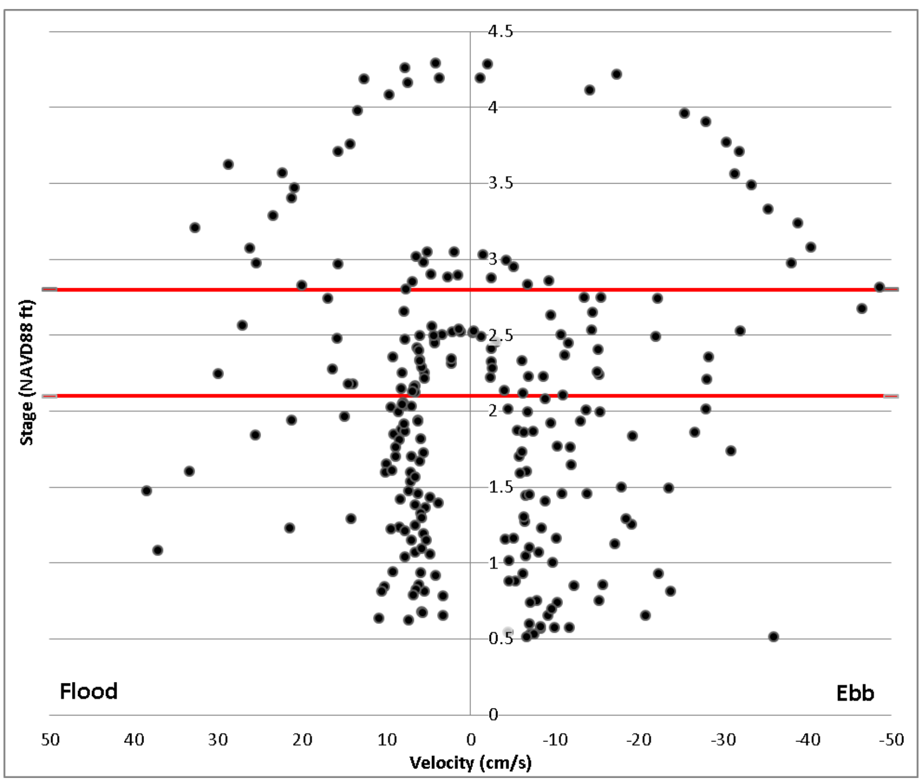


Figure 28 Lyndhurst Riverside Marsh (Mary Ann Creek): Sampled from 8/27/14 – 9/23/14, bank elevation: left 2.1 ft, right 2.8 ft.

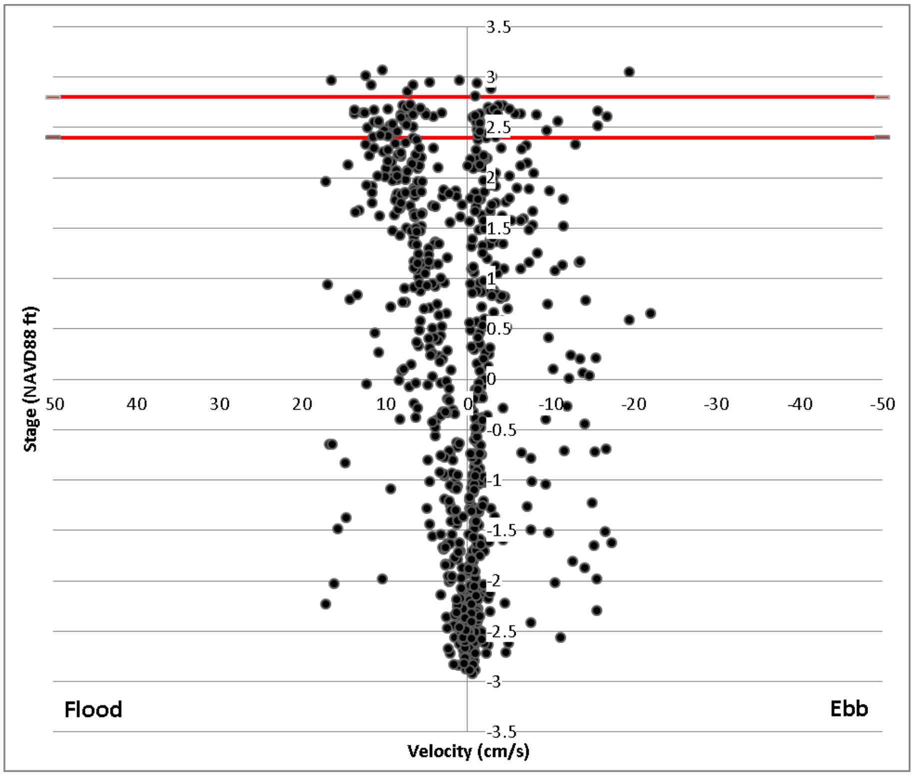


Figure 29 Riverbend Wetlands Preserve: Sampled from 7/17/14 – 7/25/14, bank elevation: left 2.8 ft, right 2.4 ft.

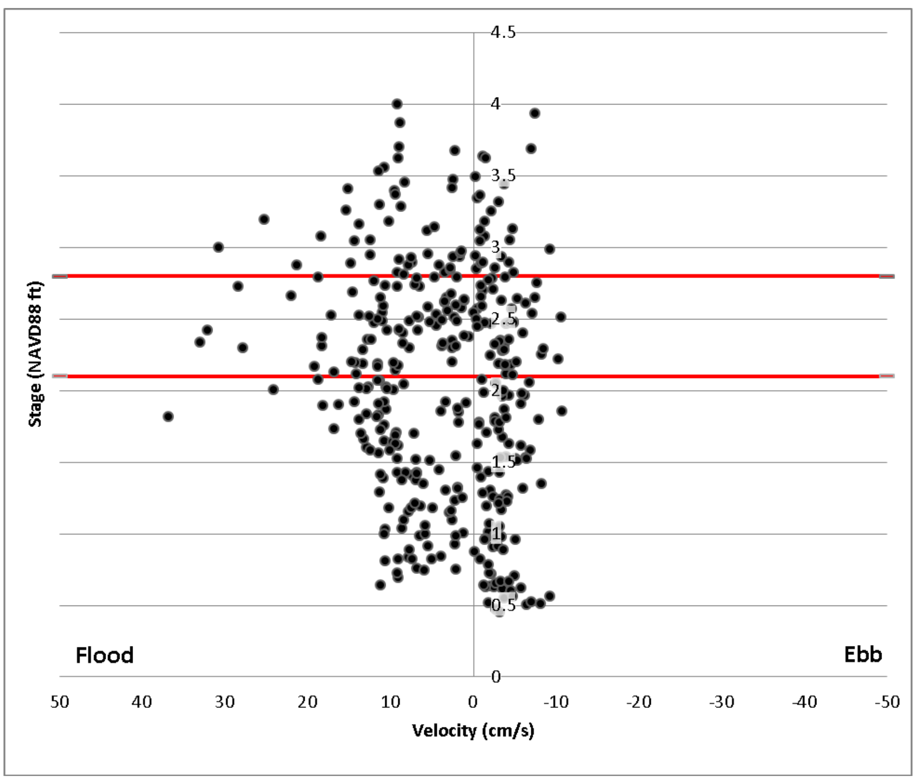


Figure 30 Bellemead Ditch: Sampled from 8/12/14 – 8/25/14, bank elevation: left 2.1 ft, right 2.8 ft. Peak flood velocity at 35 cm/s. Peak Ebb velocity occurs at the transition from overmarsh to undermarsh at 10 cm/s. Velocity is dominant during flooding.

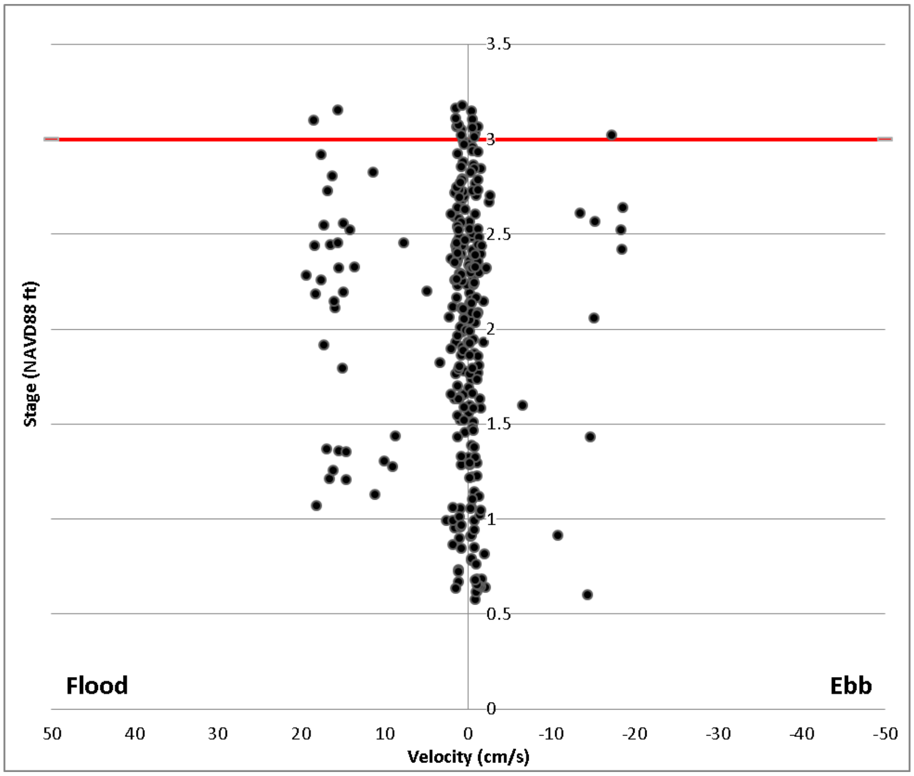


Figure 31 Fish Creek Marsh: Sampled from 7/25/14 – 7/31/14, bank elevation: left 3 ft, right 3 ft.

2.3.4 Water Residence Time

Table 16 shows water residence times calculated for the ebb cycle for each creek. Once the tide has filled the marsh the residence time is an indication on how long it takes for the water to exit the site during the ebb. Residence time should be used with caution as it omits complex mixing hydrodynamic processes occurring within the wetland such as areas of stagnant water and it's only valid for undermarsh conditions since cross sections and flow calculations assume only undermarsh conditions. Residence time is also called detention time which is a measure of the average time that water remains in the wetland. Recent evidence suggests that the calculated residence time is often much longer than the actual residence time of water flowing through a wetland due to non-uniform mixing (Kadlec and Knight, 1996; Werner and Kadlec, 1996). In this case we use residence time or detention time as a metric to compare the theoretical time that a suspended particle would remain in the system over an ebb cycle.

Site	Ebb RT (hours)
Anderson Creek	1.28
Bellemead Mitigation	6.72
Fish Creek	3.20
Hawk Property	1.61
Lyndhurst Riverside	0.67
Riverbend	1.12
Secaucus High School	0.59

Table 16 Ebb residence times (RT) in hours for each creek

Detention times were small for Secaucus High School marsh and Lyndhurst Riverside. The longest ebb retention time was found in Bellemead Mitigation. Bellemead and Fish Creek had the lowest flow velocities resulting in longer residence times. Detention times were smallest for Riverbend and Secaucus indicating that under undermarsh conditions organic matter would move at a faster rate out of these two sites compared to the other creeks.

2.3.5 Creek Profile

Creek slopes and length are shown in Table 17 and Figure 32. The longest creek surveyed was Riverbend with almost 3000 feet which also had the greatest distance between the highest and the lowest point (7 feet). Fish Creek on the other hand was the shortest creek and had the least difference between its high and low point (2.5 feet) and lowest slope (0.03%). Secaucus High School and Hawk site had the greatest slopes (0.18 and 0.17 %) respectively.

Site	Creek Slope	Length (ft)	Max Elev (ft)	Min Elev (ft)
Anderson Creek	0.03	1381	0.70	-1.50
Bellemead Ditch	0.11%	1569	1.97	-1.20
Fish Creek	0.03%	711	1.73	-0.77
Hawk Property	0.17%	1447	1.20	-1.90
Lyndhurst Riverside	0.11%	1570	1.00	-1.94
Riverbend	0.11%	3367	0.93	-6.10
Secaucus High School	0.18%	1453	0.89	-3.72

Table 17 Creek slopes and length along with maximum and minimum elevations.

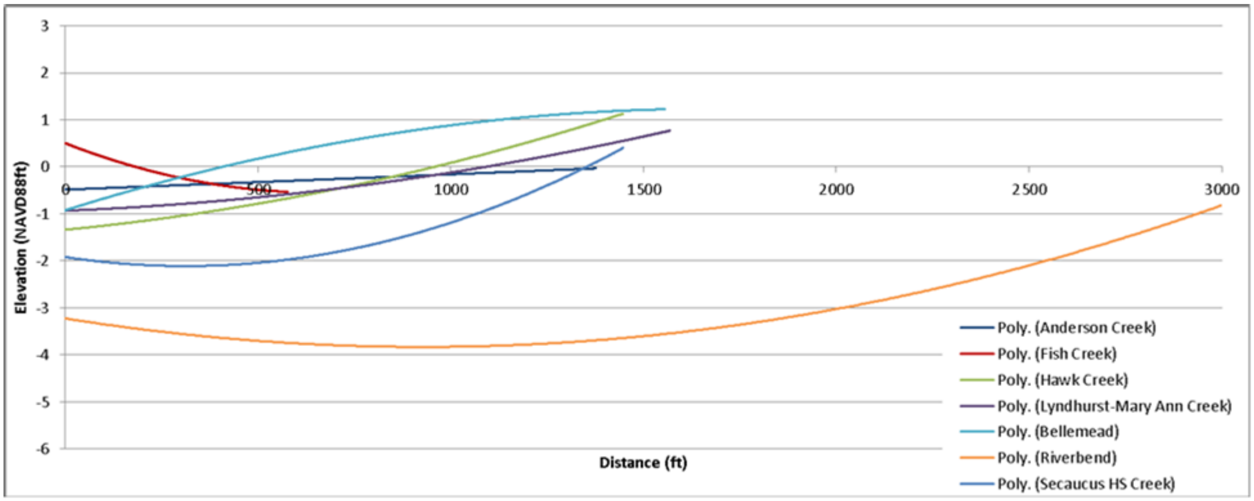


Figure 32 Slopes and lengths of creeks.

2.3.6 Bathymetry

Bathymetric rasters were created for each study area using the methods described in section 2.2.3. The following maps are a combination of bathymetric and topographical data. Surface topography was used to incorporate bank elevation with the bathymetry filling in the gap the LiDAR couldn't penetrate because of the waterbody in between. The maps below (Figure 32-38) display river bottom elevation from its lowest surveyed point to 1 ft NAVD88. Darker colors represent lower elevations.

Figure 32 Anderson Creek, 1381 linear ft in length, branches from inlet on the Hackensack River curving to the back of the marsh where it quickly fades into a low marsh area then met with a wall supporting commuter rail lines. Average creek centerline elevation is -3.41 ft NAVD88. Minimum creek centerline elevation is -1.50 ft NAVD88 and maximum elevation is 0.70 ft NAVD88.

Figure 33 Bellemead Ditch lies between the New Jersey Turnpike and the Lyndhurst Riverside marsh. A ditch separates Bellemead from Lyndhurst riverside. Both ditches flow into a low marsh zone where during abnormally high tide they converge along with Mary Ann Creek.

Figure 34 Fish Creek is the southernmost study site and is situated between the Hackensack River and active rail lines.. The creek is 711 ft in length with a minimum bottom elevation at -0.77ft and maximum at 1.73 ft.

Figure 35 Hawk Property is positioned adjacent to the flow of the Hackensack River and surrounded by industrial and residential areas and a solar power array to the south. The primary creek is 1447 ft in length with a minimum bottom elevation at -1.9 ft and maximum at 1.2 ft.

Figure 36 Lyndhurst Riverside Marsh (MaryAnn Creek) is situated to the south of Bellemead Mitigation adjacent to the Hackensack River. Minimum elevation, found on the inlet is at -6.1 ft and maximum elevation of 0.93 ft is found at the north west of the creek.

Figure 37 Riverbend Wetlands Preserve Is the longest creek surveyed at 3367 ft in length. Unlike other creeks deep troughs can be found on the sharp bends along its meandering path through the site.

Figure 38 Secaucus High School Marsh Creek is 1453 ft in length with a minimum centerline elevation at -3.72 ft and maximum centerline elevation at 0.89 ft.

2.3.7 Landfill Proximity

Landfill proximity for each site was calculated using a Euclidean distance raster (Table 18). The raster is a calculation of distance from any point to a source. The source being landfills within the Hackensack Meadowlands District (i.e.1-A, 1-D, 1-E, 15W, Avon, BCUA, Erie, Keegan, Lyndhurst, Malanka, and Rutherford Landfills). The distance from each site to each landfill was calculated individually then the resulting 13 raster were summed together (Rutherford Landfill and Malanka Landfill are broken up into two sections therefore two calculations were made).

Site	Summed Distance
Bellemead	120303
Fish Creek	156376
Harrier Meadow	118385
Hawk Property	125454
Lyndhurst Riverside	121437
Riverbend	140626
Secaucus HS	270946
Anderson Creek	130443

Table 18 Landfill proximity, higher values are farther from landfill sources.

Section III - Hyperspectral and balloon image collection and processing, image analysis and classification, calculating habitat fragmentation metrics

3.1 Introduction

One aspect of vegetation cover not captured in the floristic survey is the spatial arrangement of vegetation at each site. This involves measuring the horizontal as well as the vertical distribution of the different vegetation assemblages. Furthermore, the horizontal arrangement of vegetation in combination with the existing geography and land uses yields habitat fragmentation patterns that can be characterized by class and landscape level metrics. In this study, balloon imagery provided high resolution aerial photography that helped define vegetation training sites necessary to classify 1 meter horizontal and 5 nm spectral resolution (144 bands) hyperspectral image of the entire study area. These images were then merged with LiDAR data to obtain the final image vegetation classification products that included topography and canopy vertical information. These vegetation classification products were then merged with the current geography and together provide the input for what is called the habitat fragmentation analysis. Under this analysis, spatial distribution and characteristics of surface type classes as represented on the vegetation maps were compared among themselves – by class level metrics of total class area, number of vegetation patches, total edge, and core area – , as well as analyzed within the landscape - by landscape-level metrics of patch richness and the Shannon Diversity Index.

3.1.1 Review habitat fragmentation metrics

Overall, the size and extent of vegetation patches and the edges associated with patch boundaries are some of the most basic aspects of landscape pattern that can affect many processes. For example, although there are several effects of habitat fragmentation on plant behavior (e.g. habitat use patterns, and intra- and inter-specific interactions), these effects are caused by a reduction in habitat area and continuity and an increase in the proportion of edge-influenced habitat. The ***area of each vegetation type or class area*** as identified on the vegetation maps – i.e. CA – that represent an element of the landscape mosaic is perhaps the single most important and useful piece of information contained in the landscape. Most species have minimum area requirements: the minimum area needed to meet all life history requirements (e.g., Robbins et al., 1989). Thus, patch size information alone could be used to model species richness, patch occupancy, and species distribution patterns in a landscape, but only when relationship between different plan species or assemblages are appropriately established.

The extent of a patch (or patches collectively) could be even more important. Connectivity is considered a "vital element of landscape structure" (Taylor et al., 1993), and in terms of vegetation patches it is the "structural connectedness" of patches or habitats occupied by the same plant species or assemblages that measures physical continuity across the landscape. Continuity can be evaluated by a measure of habitat extensiveness; i.e., the extent of the reach of a contiguous patch or collection of patches on average and it is referred here as ***patch size.***

The ***amount of edge*** in a landscape is also important to many ecological phenomena. In landscape ecological investigations and in terms of vegetation patterns, this importance of spatial pattern is related to edge effects. For example exotic species intrusion into native vegetation patches or habitats start at the edges. The higher the edge length/patch area ratio, the more susceptible that particular plant assemblage is to invasion and thus habitat fragmentation.

The proportion of a patch that is affected in this manner is dependent, therefore, upon patch shape and orientation, and by adjacent habitats or assemblages. A long but narrow patch of high marsh habitat for example, could be entirely edge habitat.

Hence ***total class edge*** and ***edge length/patch area ration*** in a landscape are often the most critical piece of information in the study of fragmentation and many of the class indices directly or indirectly reflect the amount of class edge. Similarly, the total amount of edge in a landscape is directly related to the degree of spatial heterogeneity in that landscape, as the higher sum of edge length of all different habitat or assemblage patches, the more spatially diverse the landscape is.

Another crucial spatial structure in terms of survival is the ***core area***. It is defined as the area within a vegetation patch beyond some specified depth-of-edge influence (i.e., edge distance) or buffer width. Edge effects result from a combination of biotic and abiotic factors that alter environmental conditions along patch edges compared to patch interiors, and are largely affected by patch shape. For example, when edge depth is calculated as a buffer, and the area of this buffer is taken away, core area is computed. This remaining area needs to be big enough not only to contain the plant species or assemblages but support them throughout their life cycle and provide refugee and base for expansion when competing against exotic species invasion. The way *Phragmites* spreads using ***stolons*** highlights the importance of large, continuous native habitat patches. Stolons are stems that are connected to the parent plant and they grow along the soil surface and can form roots and shoots when the conditions are desirable. They allow *Phragmites* expansion to “jump over” undesirable sediment conditions – for example lower lying, more frequently inundated areas or narrow patches of high marsh - and invade areas, where the population of the species is not yet established.

Spatial diversity is another metric to assess the heterogeneity of the landscape. Diversity measures have been used extensively in a variety of ecological applications. We computed the spatial versions of the well-established Shannon-Wiener diversity index and species richness. These diversity measures are influenced by two components—richness and evenness. Richness refers to the number of different vegetation classes present; evenness refers to the distribution of area among those different types. Richness and evenness are generally referred to as the compositional and structural components of diversity, respectively. Shannon's diversity index is more sensitive to richness than evenness. Thus, rare patch types have a disproportionately large influence on the magnitude of the index.

Example of panoramic balloon photography showing the high marsh patch at Hawk Marsh July, 2014.
Photo by S. Kojak.

3.2. Methods

3.2.1 Balloon Imagery acquisition and processing

During the growing season of 2014 high resolution aerial images were taken of the marsh communities with a 14 mega pixel digital camera (Canon G1X) mounted on a tethered helium balloon platform suspended at 150 meters in the air. The camera settings were programmed depending on the day to provide clear images and to shoot every 10 seconds. The camera was moved either by boat or on foot depending on the accessibility of the site. Each individual site had a designated flight date, when the entire site was captured. Each photo covered an area of approximately 120x120 meters. The resulting digital images were then mosaicked using Adobe Photoshop® (CS 5.5) and saved in a tag image file format (TIFF) for further processing. Pre-processing was completed by rectifying the mosaics using NJDEP aerial imagery collected in 2012 at a scale of 1:2400 (1" - 200') with a 0.31 m pixel resolution. Finally, a nearest neighbor resampling method and warping procedure gave a maximum root-mean-square error (RMS) of 0.31 m with a spatial resolution of 0.15 m or better. The resulting balloon aerial image mosaics were overlaid with the locations of the vegetation survey plots (see floristics) and vegetation boundaries hand-digitized on the screen and saved as ground truth areas (shapefiles) to be used in the hyperspectral image classification.

3.2.2 Hyperspectral Image Acquisition and Pre-processing

Hyperspectral image acquisition and pre-processing was completed by Galileo Group Inc. (FL, USA) with the purpose to map the different vegetation types within the area of interest (AOI). The mission of the Galileo Group was to collect and pre-process airborne hyperspectral imagery of all seven study sites within the District. Airborne data acquisition was limited to a minimum sun elevation angle of 45 degrees and a maximum of 2 hours before or after local low tide to ensure high quality imagery. On August 5 images for the District were acquired through 17 flight lines. In this occasion approximately 10% of the AOI was covered by shadows so a second collection flight took place under clear skies on August 7, 2014 which completed three additional flight lines for a cloud and shadow free coverage of all the sites.

Technical specifications of the AISA EAGLE VNIR Hyperspectral Imaging Sensor System (400 – 1,000 nm spectral range) are 128 spectral bands for the VNIR (Visible Near Infrared) range with a spectral resolution of around 5 nm and a Ground Sampling Distance (GSD) of 1.0 m. The FOV (Field of View) was

34 degrees. An Oxford Solutions RT 3052 GPS/IMU simultaneously collected navigation data which was then used to geo-rectify the imagery with high accuracy. Table 19 shows the technical details of the two flights.

Acquisition Conditions	
5 August, 2014 (20140805)	**7 August, 2014 (20140807)**
Scattered clouds within the AOI at medium level (approx. 4000 - 5000ft)	Clear Skies
Cloud Cover (images): <1%	Cloud Cover (images): 0%
Cloud Shadows (images): <10%	Cloud Shadows (images): 0%
Acquisition Time: 10:15h – 13:01h (local time)	Acquisition Time: 10:13h – 10:28h (local time)
Solar Elevation: >45 degrees	Solar Elevation: >45 degrees
Flight Altitude: 4500ft	Flight Altitude: 4500ft
Flight Speed: 100 knots	Flight Speed: 100 knots
Flight Lines: 17	Flight Lines: 3

Table 19 Hyperspectral image acquisition conditions

Hyperspectral data was radiometrically, atmospherically and geometrically corrected. At the end of every flight line the sensor shutter was closed and 5 seconds of dark image was collected for use in dark noise removal. First the mean value of every line of the dark data is subtracted from the corresponding line of the raw data (dark noise removal or dark current removal). After the dark noise removal the raw data was calibrated to radiance units using a calibration file. Every spatial and spectral pixel is multiplied with the corresponding value in the calibration file. The focal length of the lens is 17.951 mm. The radiance units are equal to (mW/cm^2*str*um)*1000.00. Quality control was accomplished using ASD FieldSpec3 (Analytical Spectral Devices, Boulder, CO, USA) measurements from a spectral library and established quality protocols (Jiménez and Diaz-Delgado, 2015).

Calculation of the sensor head offset (Boresight correction): During the project special Boresight flight lines were flown to calculate the offset of the sensor in regards to the GPS/IMU. The calculated values (Roll, Pitch and Yaw in degrees) were used as input for the geometric correction process.

Georectified reflectance flight lines were then masked to eliminate areas of shadow, border distortion effects and to conform to the boundaries of the District. These masked lines were then combined into a single mosaic comprising the entire District. Provided ground control points (MERI 2013) of known accuracy were then used to check the geo-accuracy of the imagery. The overall geo-accuracy across the entire mosaic was found to be well within contractual parameters and clearly outperformed the targeted minimum accuracy of 3 m root mean square error (RMSE). All Data was saved in ENVI format (.dat) and projected to State Plane New Jersey, NAD83, feet.

3.2.3 Hyperspectral image Post-Processing

Using ENVI's masking tool (ENVI V. 5.0) each site was resized to match the exact boundary as defined by the Meadowlands Environmental Site Investigation Compilation (MESIC) Report (USACE, 2004). The Minimum Noise Fraction (MNF) transform was used to determine the inherent dimensionality of image data, to segregate and equalize the noise in the data, and to reduce the computational requirements for subsequent processing (for further details please refer to Artigas and Pechmann, 2010).

The Pixel Purity Index (PPI) is used to find the most *spectrally pure*, or extreme, pixels in multispectral and hyperspectral data (ENVI 5.0). The PPI image is an important intermediate product in the process. It identifies and locates the purest pixels in the scene (often less than 1% of the total number of pixels). Furthermore, the PPI image points to localities and sites that should be visited for ground truth collection and spectral measurements in the field (for further details please refer to Artigas and Pechmann, 2010).

3.2.4 Image classification

The PPI image is overlapped with the ground truth polygons that were digitized based on field surveys and balloon imagery. Pure pixels or pixels with high PPI score – i.e. most unique – were selected and their spectral profile saved in a spectral library (Figure 39). Additionally field collected spectral profiles of each habitat and dominant plant species were compared to the image derived spectral library to verify and finalize the endmember selection and save the set of endmembers as a spectra library that contains the spectral profile of all dominant habitat types and plant species. This spectral library is entered as reference spectra in the classification process (Figure 40).

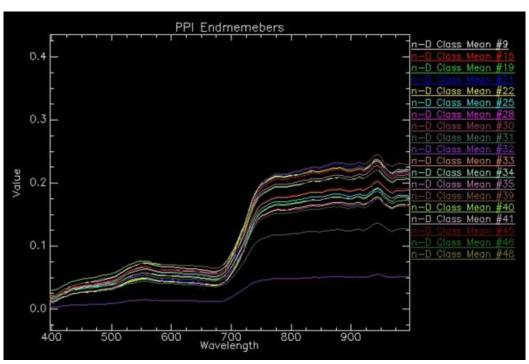


Figure 39 Spectral profiles of vegetation. Example of PPI image derived endmembers

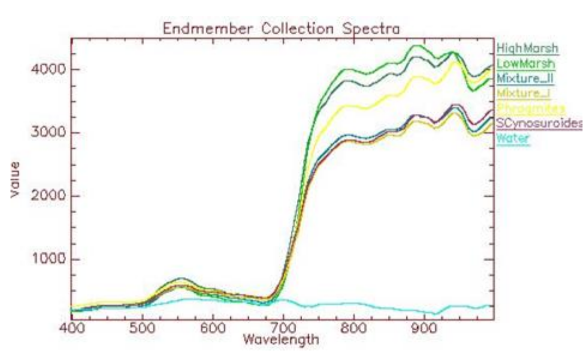


Figure 40 Field spectra verified selection of master spectra to enter in the classification procedure

ENVI provides several methods for mapping the spatial location of each of the selected endmember spectra. The Spectral Angle Mapper (SAM) matches image spectra to reference spectra (in this case the predefined spectral library) in n-dimensions. SAM compares the angle between the endmember spectrum and each pixel vector in n-dimensional space. Smaller angles represent closer matches to the reference spectrum. This technique, when used on calibrated data, is relatively insensitive to illumination and albedo effects. Before classification, the hyperspectral image was clipped using LIDAR data and according to elevation ranges defining five habitat types. The criteria for each habitat type was defined as follows: pixels 0.5 ft or lower were grouped under water/mudflat category; pixels ranging between 0.5 ft and 2.5 ft were assigned as low marsh habitat; pixels between 2.5 ft and 3.4 ft were assigned as high marsh, areas between 3. 4 ft and 3.6 ft were identified as upland transition zone and pixels with elevations greater than 3.6 ft were grouped as upland. Each habitat type was classified separately resulting in a final vegetation image for each site.

3.2.5 Habitat Fragmentation Metrics

The objective of the habitat fragmentation metrics is to merge the vegetation classification images with geographic datasets to arrive at distinct class level and landscape level metrics of impairment. FRAGSTATS 4.0 software – an open source software – was used to compute a wide variety of class level and landscape level metrics for categorical map patterns (McGarigal and Marks, 1995). FRAGSTATS computes several statistics for each class (vegetation or assemblage type) and for the landscape as a whole. The hyperspectral image classification of the 6 wetland sites (Bellemead Mitigation and Lyndhurst Riverside Marsh were again combined into one site for the purpose of the analysis) were converted into signed integers where each distinct vegetation class formed its own individual patch.
As discussed in the introduction of this section, class metrics were computed to assess the spatial relationship among the various assemblages inhabiting the study sites and landscape metrics were computed to assess the composition and heterogeneity of the landscape along with level of habitat fragmentation.

Class level metrics included**:** **CA** – Total Class Area; **NP** - Number of Patches; **PD** - Patch Density; **TE** - Total Edge; **ED** - Edge Density; **PAFRAC** - Perimeter-Area Fractal Dimension; **TCA** - Total Core Area; **CPLAND** - Core Area Percent of Landscape; **NDCA** - Number of Disjunct Core Areas.

Classified vegetation maps were used as thematic maps for this analysis. Area measures of vegetation classes as defined on the vegetation maps yielded in computing CA, NP and PD. Figure 41 shows the horizontal distribution of the high marsh vegetation (green) within the marsh boundaries with shades of grays representing other vegetation assemblages and surface types. Each patch surrounded by a different type of assemblage or habitat represents a distinct patch.

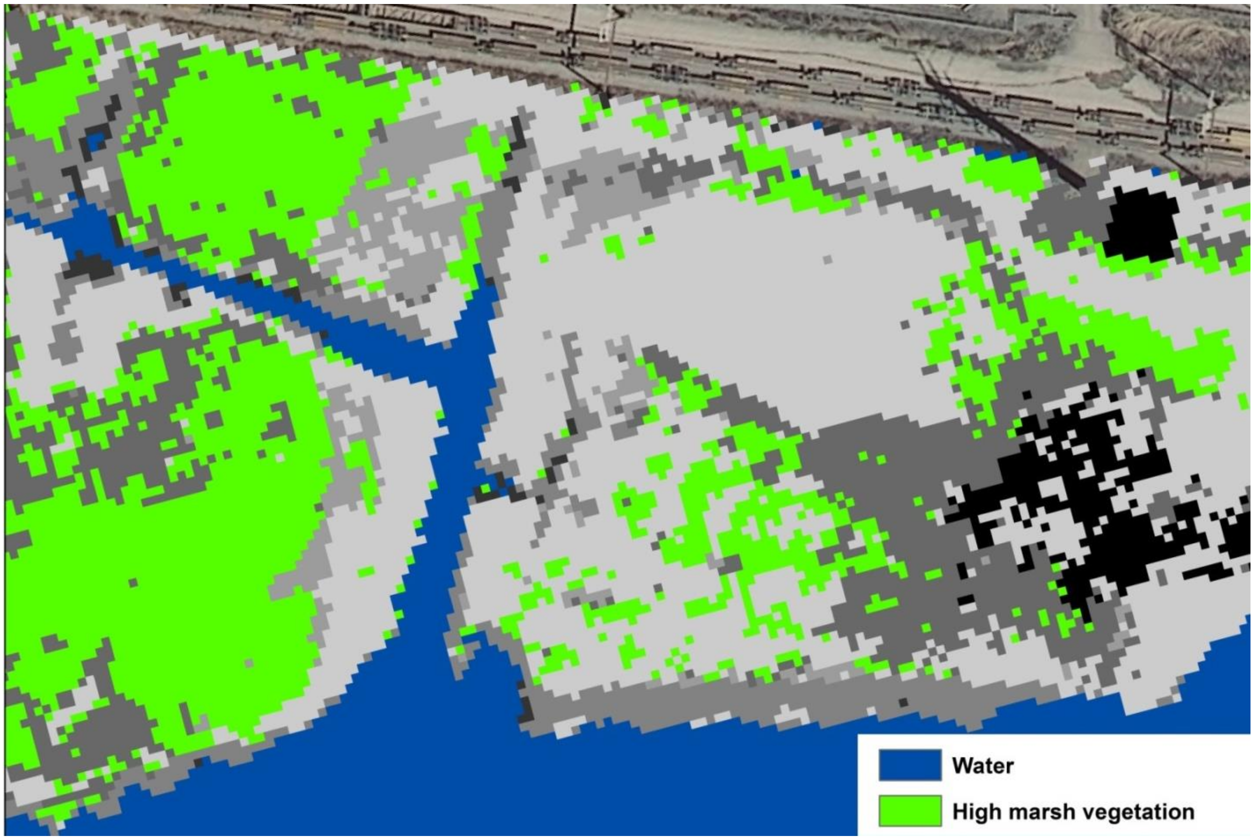


Fig 41 Distribution of high marsh patches at Fish Creek Marsh based on the 2014 hypespectral imagery.

Boundaries of the vegetation classes as defined by the vegetation maps represented the edges of the vegetation patches and provided measures for TE, ED. Figure 42 shows the same high marsh area but in this case red, bold lines highlight the patch edges. The length and density of those lines were used in computing TE and ED.

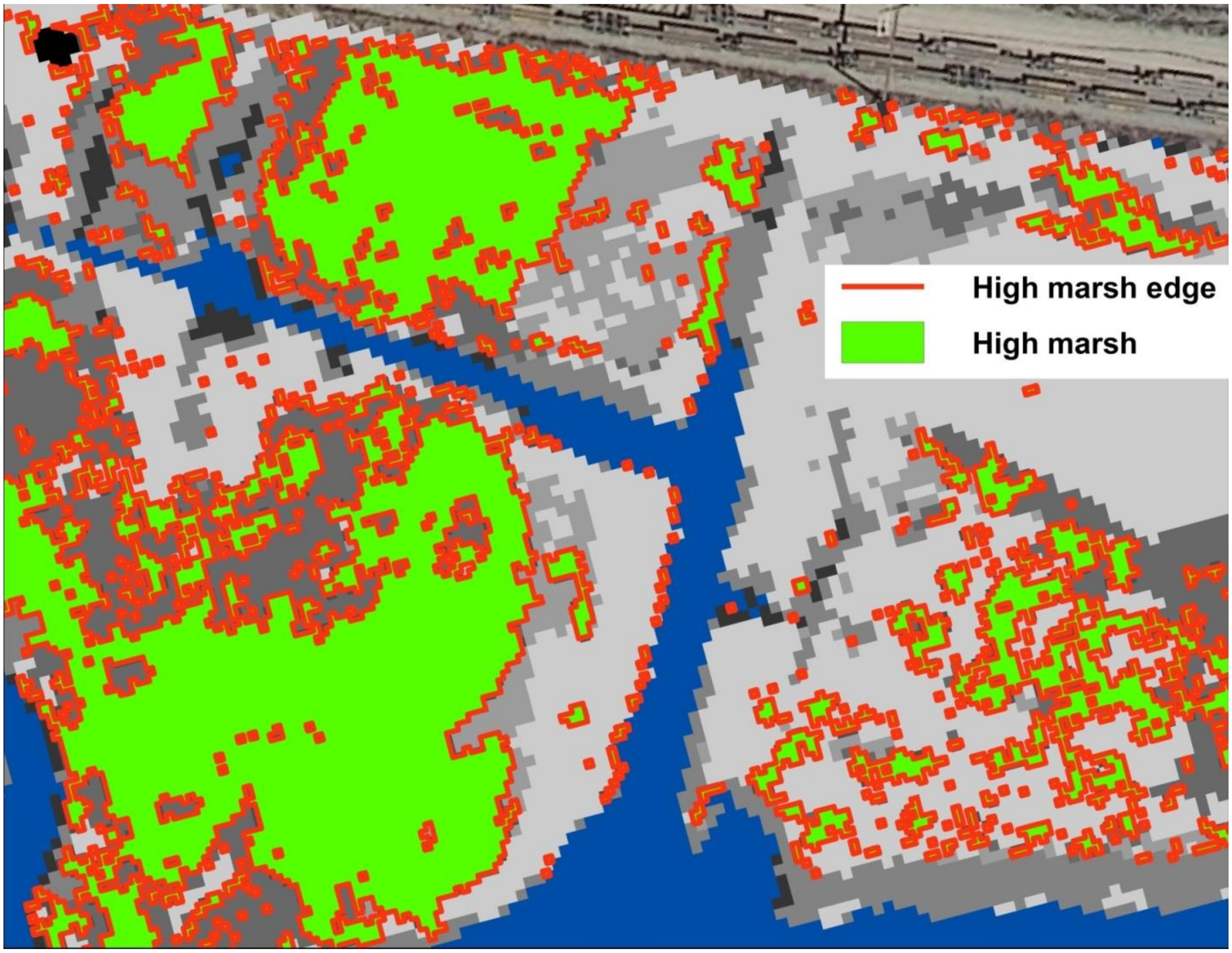


Fig. 42 A spatial representation of high marsh edge length at Fish Creek Marsh

For core area (TCA) metrics buffers for each vegetation types were defined based on our previous knowledge of elevation gradient, sediment geohydrology and salinity gradient at the study site, as well as taking into consideration competition between native high marsh and *P. australis* stands. In this regard broader buffers were calculated between high marsh and *P. australis* or *P. australis*-high marsh mix, than between low marsh and high marsh, or high marsh and shrub communities. There were no buffers defined between habitat types that are not adjacent. Table 20 shows an example of the user defined buffer matrix for the Secaucus High School Marsh.

As for computing the actual metrics edge depth matrices as shown above outlined the buffer area on the vegetation maps for each distinct vegetation patch. Figure 43 shows a spatial example of how edge depth is computed using the thematic vegetation maps. The area displays the same high marsh habitats at Fish Creek This buffer was then placed over the patch as a mask (beige color). After this mask was eliminated from the original patch, the remaining patch constituted the actual core area (green).

Lastly the combination of the previous metrics yielded values of PAFRAC, CPLAND and NDCA.

	Water	Mud	SA	LMHMmix	PH	PHHMmix	HM	SC
Water	0	10	3	3	6	0	0	0
Mud	10	0	10	3	6	0	3	0
SA	3	3	0	10	3	0	10	0
LMHMmix	0	0	10	0	3	10	3	3
PH	6	3	3	3	0	10	10	0
PHHMmix	6	0	10	10	10	0	10	3
HM	0	3	10	3	10	10	0	3
SC	0	0	0	3	0	3	3	0

Table 20. Edge depth matrix for Secaucus – values are in meters.
Vegetation codes: SA – *Spartina alterniflora*, **PH –** *Phragmites australis*, **LMHMmix –** low marsh – high marsh mixture**, PHHMmix –** High marsh – *P. australis* mixture**, HM –** high marsh, **SC** – *Spartina cynosuroides*, **SHHMmix –** high marsh – shrub mixture, **SHPHmix –** shrub – *P. australis* mixture.

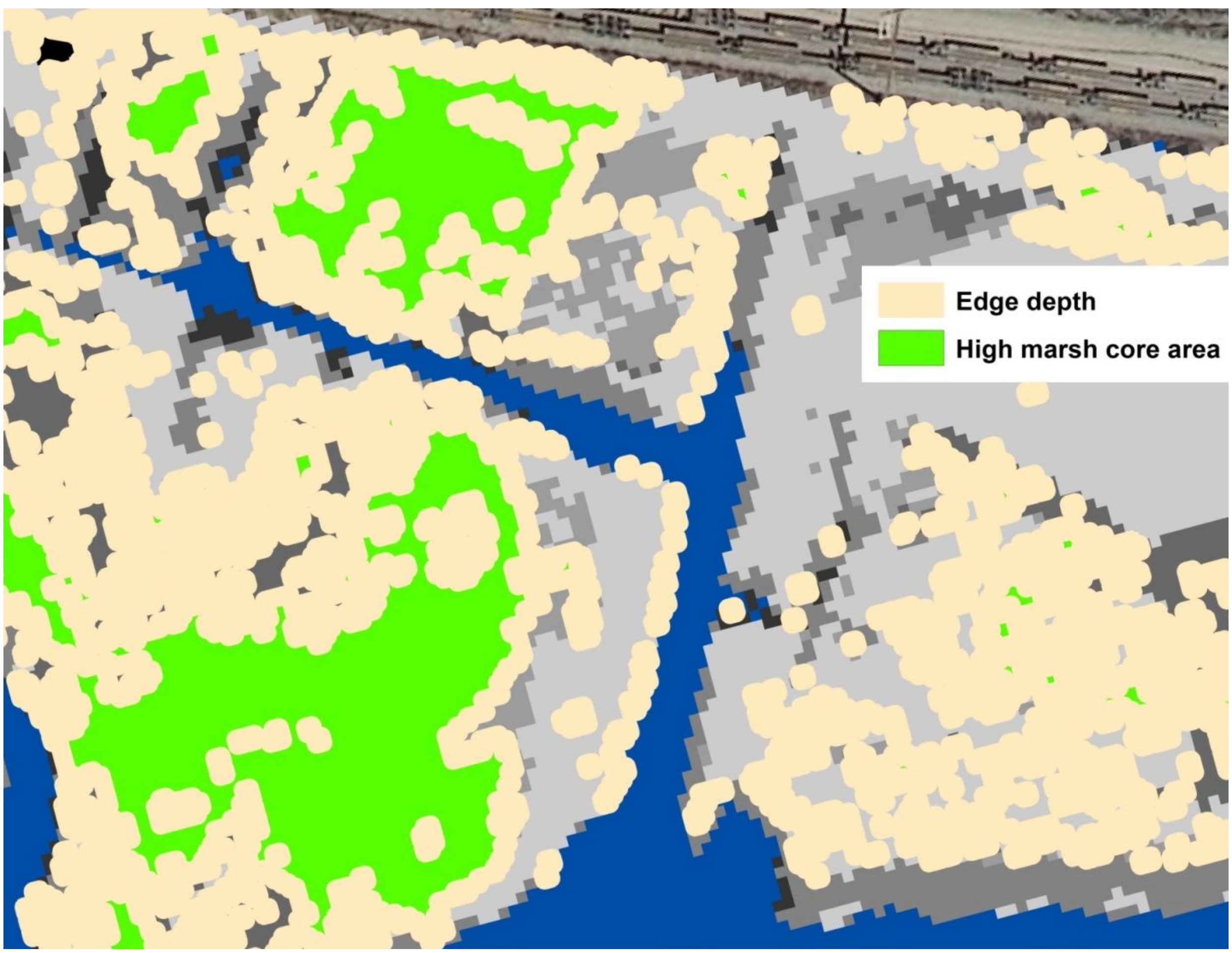


Fig. 43 Spatial representation of edge depth and core area of the high marsh habitat at Fish Creek Marsh

Class level metrics calculated from the hyperspectral image patches are shown in Table 21.

Total Class Area (CA)	
$CA = \sum_{j=1}^{n} a_{ij}\left(\frac{1}{10,000}\right)$	a_{ij}= area (m^2) of patch ij
Description	CA equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by 10,000 (to convert to hectares); that is, total class area.
Range	CA> 0 without limit. CA approaches 0 as the patch type become increasing rare in the landscape. CA = Total area (TA) when the entire landscape consists of a single patch type; that is, when the entire image is comprised of a single patch.
Number of Patches (NP)	
NP= n_i	n_i= is the number of patches within each distinct landscape (class) type
Description	NP of a particular patch type is a simple measure of the extent of subdivision or fragmentation of the patch type.
Range	NP > 0 without limit. NP approaches 0 as the patch type becomes increasing rare in the landscape
Patch Density (PD)	
PD= $\frac{n_i}{A}$ **=(10,000)x(100)**	n_i= is the number of patches within each distinct landscape (class) type A – total landscape area
Description	PD equals the number of patches of the corresponding patch type divided by total landscape area
Range	PD > 0, constrained by cell size. PD is ultimately constrained by the grain size of the raster image, because the maximum PD is attained when every cell is a separate patch. Therefore, ultimately cell size will determine the maximum number of patches per unit area. However, the maximum density of patches of a single class is attained when every other cell is of that focal class (i.e., in a checker board manner; because adjacent cells of the same class would be in the same patch).
Total Edge (TE)	
$TE = \sum_{k=1}^{m} e_{ik}$	e_{ik}= is the total length of edge in landscape involving patch type
Description	At the class and landscape levels, *total edge* (TE) is an absolute measure of total edge length of a particular patch type (class level) or of all patch types (landscape level).
Range	TE> 0 without limit. TE approaches 0 as the patch type become increasing rare in the landscape.
Edge Density (ED)	
$ED = \frac{\sum_{k=1}^{m} e_{ik}}{A}(10,000)$	e_{ik}= is the total length of edge in landscape involving patch type A – total landscape area
Description	ED equals the sum of the lengths (m) of all edge segments involving the corresponding patch type, divided by the total landscape area (m2).
Range	ED ≥ 0, without limit. ED = 0 when there is no class edge in the landscape; that is, when the entire landscape and landscape border, if present, consists of the corresponding patch type.

Table 21 Calculation and brief description of the class level metrics used in this study (retrieved December 12, 2015, from the University of Massachusetts, Amherst, Landscape Ecology Program Web site: http://www.umass.edu/landeco/research/fragstats/fragstats.html).

Landscape level metrics included: **TA** - Total Marsh Area; **NP** - Number of Patches; **TCA** - Total Core Area; **NDCA** – Number of Disjunct Core Areas; **DCAD** - Disjunct Core Area Density, **PR** – Patch Richness; **SHDI** – Shannon Diversity Index; **FRAC**-Fractal Dimension Index

The combination of the class level metrics were summarized for calculating similar metrics at landscape level.

Landscape level metrics calculated from the hyperspectral image patches are shown in table 22.

Fractal Dimension Index (FRAC)		
$FRAC = \frac{2 \ln(.25\, p_{ij})}{\ln a_{ij}}$		p_{ij} = perimeter (m) of patch ij. a_{ij} = area (m^2) of patch ij.
Description	FRAC equals 2 times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m2); the perimeter is adjusted to correct for the raster bias in perimeter.	
Range	1 ≤ FRAC ≥ 2 A fractal dimension greater than 1 for a 2-dimensional patch indicates a departure from Euclidean geometry (i.e., an increase in shape complexity). FRAC approaches 1 for shapes with very simple perimeters such as squares, and approaches 2 for shapes with highly convoluted, plane-filling perimeters.	
Patch Richness		
PR= m		m = number of patch types (classes) present in the landscape, excluding the landscape border if present.
Description	PR equals the number of different patch types present within the landscape boundary.	
Range	PR ≥ 1 without limit.	
Shannon's Diversity Index (SHDI)		
$SHDI = -\sum_{i=1}^{m} (P_i * \ln P_i)$		P_i = proportion of the landscape occupied by patch type (class) i.
Description	SHDI equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion. Note, Pi is based on total landscape area (A) excluding any internal background present.	
Range	SHDI ≥ 0, without limit SHDI = 0 when the landscape contains only 1 patch (i.e., no diversity). SHDI increases as the number of different patch types (i.e., patch richness, PR) increases and/or the proportional distribution of area among patch types becomes more equitable.	
Total Core Area (TCA)		
$TCA = \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij}^{c} \left(\frac{1}{10{,}000} \right)$		a_{ij}^{c}= core area (m^2) of patch ij based on specified edge depth (m).
Description	TCA equals the sum of the core areas of each patch (m2), divided by 10,000 (to convert to hectares).	
Range	TCA ≥ 0, without limit. TCA = 0 when every location within every patch is within the specified depth-of edge distance(s) from the patch perimeters. TCA approaches total landscape area as the specified depth-of-edge distance(s) decreases and as patch shapes are simplified.	

Number of Disjunct Core Area (NCAD)		
$$NDCA = \sum_{i=j}^{m} \sum_{j=1}^{n} n_{ij}^{c}$$		n_{ij}^{c} = number of disjunct core areas in patch ij based on specified edge depths (m).
Description	NDCA equals the sum of the number of disjunct core areas contained within each patch of the corresponding patch type; that is, the number of disjunct core areas contained within the landscape.	
Range	NDCA ≥ 0, without limit. NCA = 0 when TCA = 0 (i.e., every location within every patch is within the specified depth-of-edge distance(s) from the patch perimeters); in other words, when there are no core areas. NDCA > 1 when, due to patch size and shape, at least one core area exists.	
Disjunct Core Area Density (DCAD)		
$$DCAD = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} n_{ij}^{c}}{A} (10{,}000)(100)$$		n_{ij}^{c} = number of disjunct core areas in patch ij based on specified edge depths (m). A – total landscape area (m^2)
Description	DCAD = 0 when TCA = 0 (i.e., every location within every patch is within the specified depth-of-edge distance(s) from the patch perimeters); in other words, when there are no core areas. DCAD > 1 when, due to patch size and shape, at least one core area exists.	
Range	DCAD ≥ 0, without limit. DCAD = 0 when TCA = 0 (i.e., every location within patches of the corresponding patch type are within the specified depth-of-edge distance(s) from the patch perimeters); in other words, when there are no core areas.	

Table 22 Calculation and brief description of the landscape metrics used in this study (retrieved December 12, 2015, from the University of Massachusetts, Amherst, Landscape Ecology Program Web site: http://www.umass.edu/landeco/research/fragstats/fragstats.html).

3.3 Results

3.3.1 Balloon Imagery

Imagery was collected in two sets with some sites revisited. The first set collected in August 2013 and the second set ranging from June to August 2015. Due to high tension transmission lines on Fish Creek and Riverbend, our movement on the ground was limited. Fish Creek was captured in only panoramic mode and the northern end of Riverbend was not captured orthogonally.

The resulting rectified pixel resolution ranged from 2.2in – 4.5in with Fish Creek being omitted due to only having panoramic images (Table 23).

Site	Date Collected	Image Type	Pixel resolution (inch)
Bellemead Mitigation	8/5/2013	Orthoginal / Panoramic	4.5
Fish Creek Marsh	6/17/2015	Panoramic	N/A
Harrier Meadow	8/15/2013 & 8/14/2015	Orthoginal / Panoramic	3.4
Hawk Property	8/5/2013	Orthoginal	3.7
Lyndhurst Riverside Marsh	8/5/2013	Orthoginal / Panoramic	4.5
Riverbend Wetland Preserve	8/5/2013	Orthoginal	2.2
Secaucus High School Marsh	8/21/2013 & 8/28/2015	Orthoginal / Panoramic	3.6

Table 23 List of sites captured by balloon imagery with date collected image angle type and mosaic pixel resolution.

3.3.2 Image Classification

3.3.2.1 Bellemead Mitigation and Lyndhurst Riverside Marsh

Bellemead Mitigation is a 16 acre mitigated marsh that is adjacent to the 40 acre Lyndhurst Riverside Marsh which is a natural area (Figure 1). Part of Bellemead was enhanced in 1990. Given their side by side location, in terms of their vegetation classification they were processed as one unit. The hyperspectral vegetation classification supported the field survey by finding once again the invasive *P. australis* (common reed) dominant in both marsh areas. Pure patches of high marsh habitats consist of *S. patens* and *D. spicata* however, in contrast to field surveys our classification technique did not detect open patches of pure high marsh in the Bellemead site, only high marsh reed mixtures were found. The classification method was successful in delineating mixtures of high marsh and common reed on the Lyndhurst Riverside side, where the mixture ratio was determined to be 50:50. For the upland and upland transition areas, the classification method delineated shrub communities and tree dominated communities that were labeled as shrub and upland. Both sites are heavily invaded with common reed occupying approximately 48% of the area. Out of the remaining 52%, water and mud flats take up approximately 4%, leaving the remaining area (48%) to native vegetation. Overall, vegetation covers 90% while the remaining area (mud and water) make up 10%. Table 24 shows the detailed statistics for vegetation cover and habitat size. Figure 44 shows the distribution of the dominant species and habitat types for Bellemead and Lyndhurst.

dominant vegetation	**Acre**	**% cover**	**Total *P. australis* *(acre)***	**Total *P. australis* *(%)***
Water	3.10	5		
Mud	0.76	1		
Low marsh - *Spartina alterniflora*	3.02	5		
Phragmites australis	18.4	32	27.7	48
High marsh and *Phragmites australis* mixture	18.5	32		
High marsh – *S. patens, Distichlis spicata*	9.89	17		
Shrub	2.47	4		
Upland	1.24	2		
Vegetated surface	**51.5**	**90%**		
Non-vegetated surface	**5.9**	**10%**		

Table 24 Summary of vegetation distribution and colonization at Bellemead and Lyndhurst

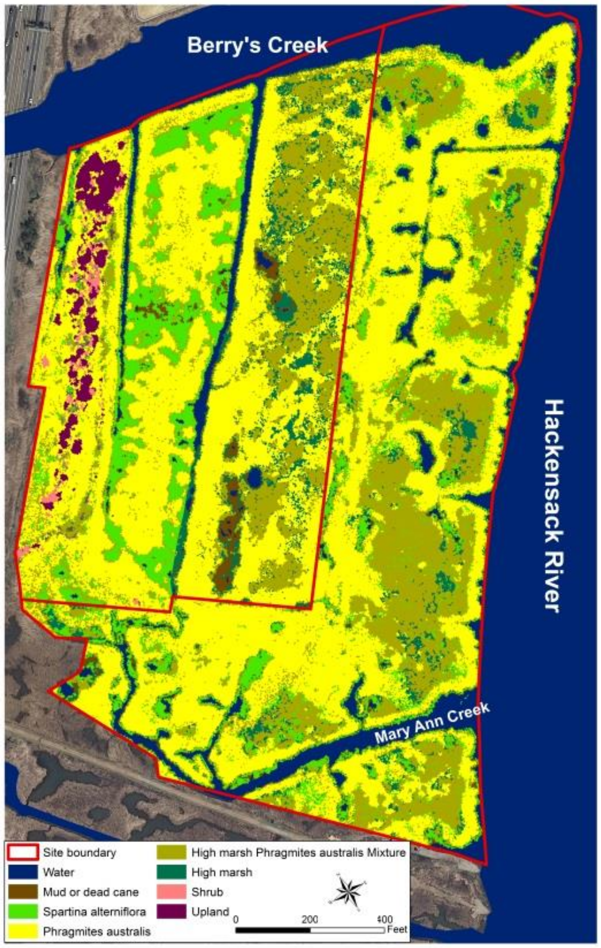


Figure 44 Vegetation map of Bellemead and Lyndhurst marsh

3.3.2.2 Fish Creek Marsh

Fish Creek Marsh is a 26 acre natural site located in the lower part of the Hackensack River (Figure 1). The site consists of high marsh, upland and transitional areas. The results of the hyperspectral classification show that high marsh types cover the largest percentage of the area with 35%. The *Phragmites australis* cover (38%) is from the fringe areas of the site. Low marsh is found only near the creek and on the riverside. The upland area is small and surrounded by dense shrub dominated by *Baccharis halimifolia*. The native vegetation covers 44% of the site, while the invasive reed grows on 38% of the site and mudflat and water makes up for the remaining 18%.

Table 25 shows the detailed statistics for vegetation cover and habitat size. Figure 45 shows the distribution of the dominant species and habitat types Fish Creek.

Dominant vegetation/habitat	Acre	% cover	Total *P. australis* (acre)	Total *P. australis* (%)
Water	4.43	17		
Mud	0.29	1		
Low marsh – *Spartina alterniflora*	2.06	8		
Phragmites australis	9.61	37	9.82	38
High marsh *Phragmites australis* mixture	0.41	2		
High marsh – *S. patens, Distichlis spicata*	5.56	22		
High marsh shrub mixture –*S. patens, Baccharis halimifolia*	3.17	12		
Upland	0.25	1		
Building	0.06	0.2		
Vegetated surface	**20.6**	**80**		
Non-vegetated surface	**5.21**	**20**		

Table 25 Summary of vegetation distribution and colonization at Fish Creek

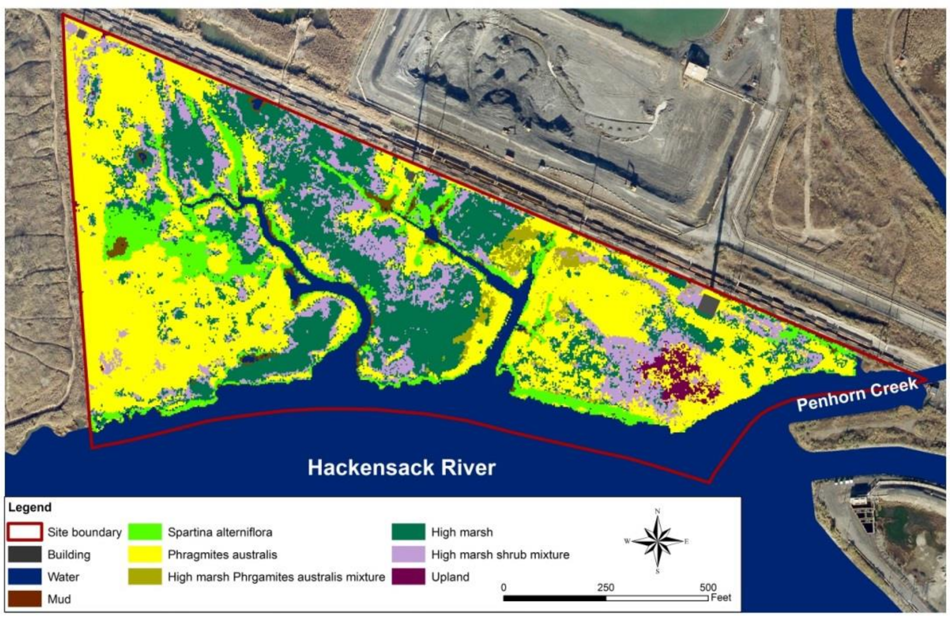


Figure 45 Vegetation map of Fish Creek

3.3.2.3 Harrier Meadow

Harrier Meadow is a 77 acre site located on the western edge of the District (Figure 1). A portion of the site was restored in 1998. The site consists of high marsh and transitional uplands dominated by shrubs and trees and meadow areas. The site is dominated by the *B. halimifolia* shrub community and dense mixtures of common reed and shrub which together make up 48% of the site. High marsh covers 10% of the area either as open patches or in mixtures with the reed. The total *P. australis* cover amounts to only 17%. Overall 74% of the area is covered by vegetation while the remaining water, mud and bare earth surfaces make up 26%. Table 26 shows the detailed statistics for vegetation cover and habitat size. Figure 46shows the distribution of the dominant species and habitat types for Harrier Meadow.

Dominant vegetation/habitat	**Acre**	**% cover**	**Total *P. australis* *(acre)***	**Total *P. australis* *(%)***
Water	12.3	26		
Mud	1.4	3		
Phragmites australis	1.7	4	8.3	17
High marsh *Phragmites australis* mixture	2.1	4		
High marsh	3.7	8		
Meadow – High marsh upland transition	0.6	1		
Shrub – *Baccharis halimifolia*	11.8	25		
Shrub *Phragmites australis* mixture	2.2	23		
Upland	11.0	5		
Trail	1.2	3		
Building	0.02	0.04		
Vegetated surface	**35.63**	**74%**		
Non-vegetated surface	**12.34**	**26%**		

Table 26 Summary of vegetation distribution and colonization at Harrier Meadow

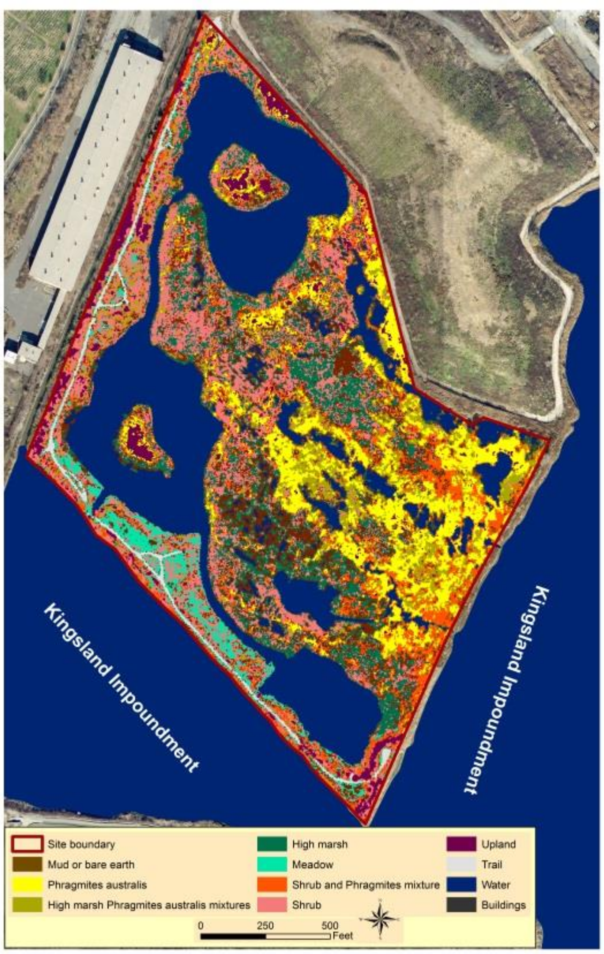


Figure 46 - Vegetation map of Harrier Meadow

3.3.2.4 Hawk Property

The Hawk property is a narrow triangular shape bordered between the Hackensack River and County Road Extension in Secaucus (Figure 1). The high marsh plant community consists of *Distichlis spicata* and *Spartina patens* with sporadic *Baccharis* at higher elevation and *Phragmites australis* mixing in from the edges while the common reed forms a dense border around the high marsh (Figure 47). Along the river's edge there is a strip of *Spartina alterniflora* which transitions to a thick stand of *P. australis* after just a few feet landward. The upland area is a mixture of tree and shrub vegetation. The vegetation classification mapped the smooth cordgrass strip along the river and correctly identified the high marsh and common reed stands. Mainly due to a leaf shadow effect, the algorithm could not differentiate between either tree or shrub species, instead they were assigned to an upland and shrubs category. According to the image classification, the dominant species is the invasive *P. australis* covering 42% of the site. Upland and transition vegetation covers approximately ¼ of the site and high marsh and low marsh shares the rest with mud and the creeks. Overall, vegetation covers 83% of the site while mud and bare earth surfaces make up the remaining 17%. Table 27 shows the detailed statistics for vegetation cover and habitat size. Figure 47 shows the distribution of the dominant species and habitat types for Hawk.

Dominant vegetation/habitat	**Acre**	**% cover**	**Total *P. australis* *(acre)***	**Total *P. australis* *(%)***
Water	3.73	11		
Mud	1.98	6		
Low marsh - *Spartina alterniflora*	2.33	7		
Phragmites australis	12.79	39	13.8	42
High marsh *Phragmites australis*	1.98	6		
High marsh – *S. patens*	2.89	9		
Weedy meadows	1.23	4		
Shrub	2.30	7		
Upland	3.65	11		
Vegetated surface	**27.3**	**83%**		
Non-vegetated surface	**5.6**	**17%**		

Table 27 – Summary of vegetation distribution and colonization at Hawk Marsh

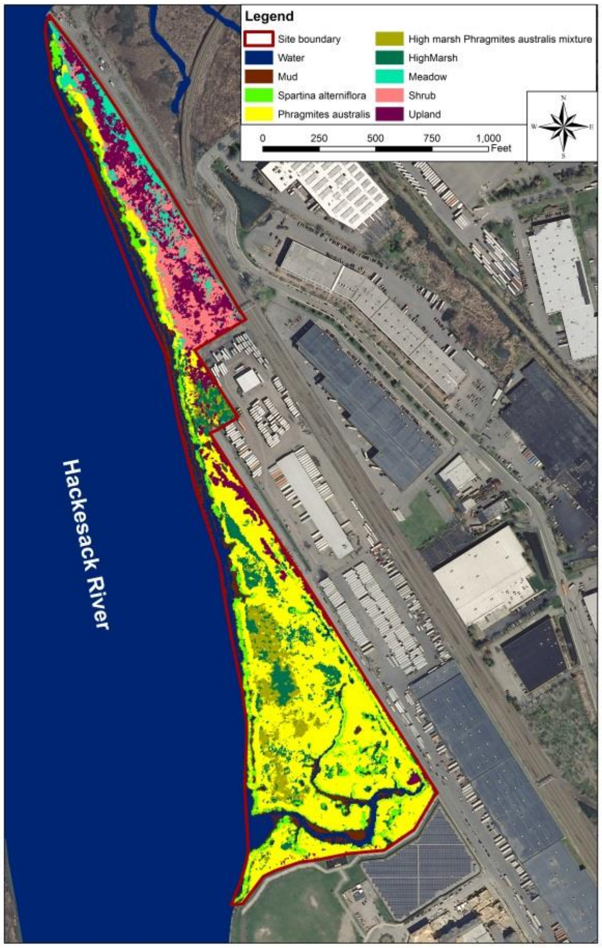


Figure 47 Vegetation map for Hawk site

3.3.2.5 Riverbend Wetlands Preserve

Riverbend is undeveloped and directly adjacent to the Malanka Landfill (Figure 1). Portions of the site currently support a mixture of native high saltmarsh vegetation, dominated by saltmeadow cordgrass (*S. patens*). Other areas consist of open water and dense monocultures of common reed (*P. australis*). The site was purchased by NJMC (now NJSEA) in December 1996 and has been a candidate site for ecological enhancement since then. The vegetation is mainly made up of high and low marsh with a strip of trees on the landfill border. The high marsh has a mixture of *S. patens* and *D. spicata*. *Spartina alterniflora* grows in the low marsh and near the river, and is beginning to grow as a mixture in the high marsh. Common reed is the dominant vegetation growing as a dense monoculture at the fringes of the site. The classification couldn't separate either the low marsh or the high marsh mixture and the *Salicornia depressa* stands with acceptable accuracy, hence these were marked as low marsh and high marsh respectively. Once again the invasive common reed dominates the site covering 50% of the total area. Overall, vegetation covered 90% of the site while mud and water made up the remaining 10%. Table 28 shows the detailed statistics for vegetation cover and habitat size. Figure 48 shows the distribution of the dominant species and habitat types for Riverbend.

Dominant vegetation/habitat	**Acre**	**% cover**	**Total *P. australis* *(acre)***	**Total *P. australis* *(%)***
Water	2.54	4		
Mud	1.48	2		
Low marsh – *Spartina alterniflora*	3.84	6		
Phragmites australis	25.08	42	29	50
High marsh *Phragmites australis* mixture	8.80	15		
High marsh – *Spartina patens*	17.53	29		
Upland	0.19	0.32		
Vegetated surface	**53.34**	**90%**		
Non-vegetated surface	**6.12**	**10%**		

Table 28 Summary of vegetation distribution and colonization at Riverbend

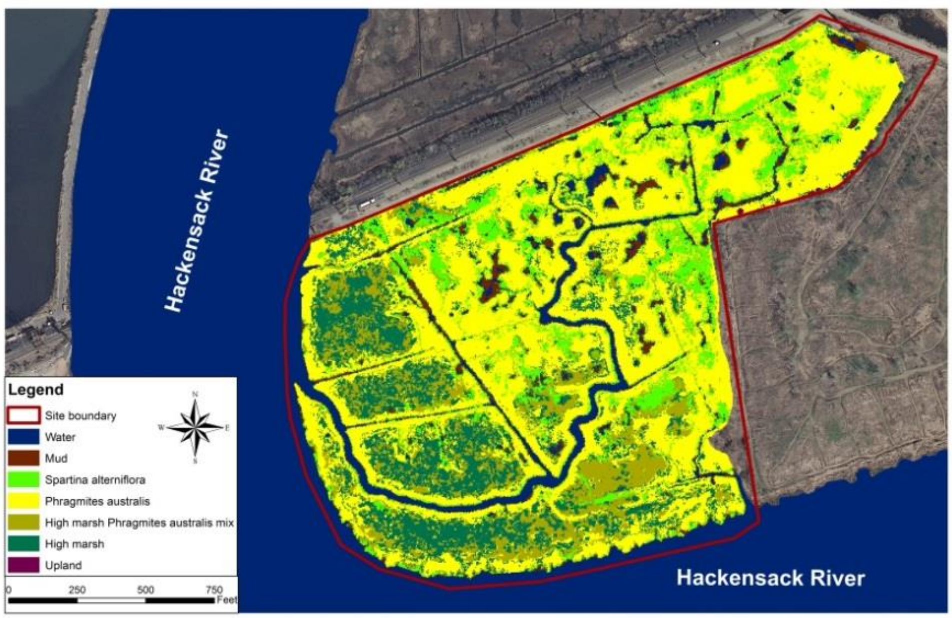


Figure 48 Vegetation map for Riverbend

3.3.2.6 Secaucus High School Marsh (SHS)

The SHS is a 36 acre restored tidal salt marsh in the town of Secaucus (Figure 1). The site used to be a *P. australis* monoculture which was reconstructed in a combination of high and low marsh. The ecological enhancement involved removing approximately 0.5 m of surface sediments. The ecological enhancement included the construction of two high-marsh areas totaling approximately 1.6 acre by raising the elevation of the selected areas with clean material that contained no reed rhizomes. The remaining area was left as low marsh. The classification procedure identified the low marsh and high marsh communities and was able to distinguish between common reed and *S. cynosuroides* as well. 64%

of the site is covered by low marsh with muddy areas mixing in at 6%. The high marsh islands are dominated by *S. patens, S. cynosuroides,* and *D. spicata* with ~13.5% coverages. *P. australis* is present in mixtures with a 7% total coverage. Overall 89% of the site is covered by vegetation with mud and bare earth surfaces making up the remaining 11%. Table 29 shows the detailed statistics for vegetation cover and habitat size. Figure 49 shows the distribution of the dominant species and habitat types for SHS.

Dominant vegetation/habitat	**Acre**	**% cover**	**Total *P. australis (acre)***	**Total *P. australis (%)***
Water	1.77	6		
Mud and mudflats	2.39	8		
Low marsh - *Spartina alterniflora*	19.8	64		
Low marsh and high marsh mixture	0.92	3		
Phragmites australis	1.56	5	2.05	7
High marsh and *Phragmites australis* mixture	0.98	3		
High marsh – *S. patens, S. cynosuroides, Distichlis spicata*	2.23	7		
S. cynosuroides	1.46	5		
Non-vegetated surface	**3.57**	**11%**		
Vegetated surface	**27.51**	**89%**		

Table 29 Summary of vegetation distribution and colonization at Secaucus

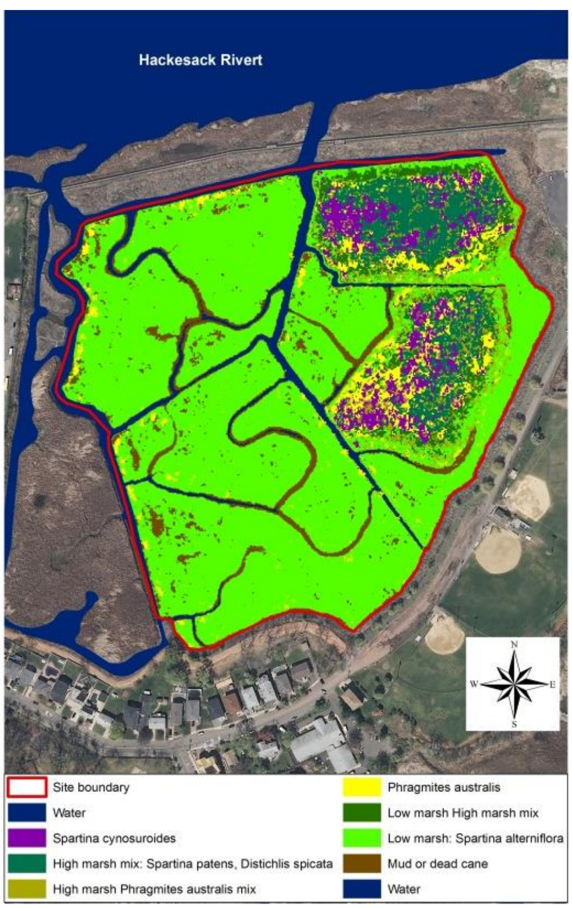


Figure 49 Vegetation map for Secaucus

3.3.3 Results of Class Level Metrics

For all the sites except Secaucus, *P. australis* and *P. australis* mixtures are the most dominant assemblage types according to Total Area (CA values, range: 42 -110, Table 30). Edge metrics as in Total Edge (TE) and Edge Density (ED) show the same trend, which may suggest that *P. australis* being a cosmopolitan species and insensitive to edge effects has been establishing smaller patches within native habitats and trying to expand from there. Hence sites with high *P. australis* cover may be subject to further common reed expansion. On the other hand native assemblage types such as high marsh show a relatively high number of patches (NP) and high patch density at all sites except again Secaucus, which predicts that this habitat type is highly fragmented. Low marsh vegetation (SA) at Riverside and Riverbend shows the same trend, while at Hawk and Secaucus it seems to be stable. Fish Creek is an interesting case, based on the total area and number of patches, low marsh seems to be a series large connected patches, but when looking at the edge metrics (TE in particular), the relative long length of edges predict vulnerability. Shrub and upland vegetation shows insignificant fragmentation except at Harrier Meadow, where high values for NP, TE, ED show that the habitat is not continuous.

Total Core Area (TCA) and Core Area Percent of Landscape (CPLAND) values, again *Phragmites* and *Phragmites mixtures* are the more stable ones by having the highest percentage of core areas not affected by edge effects. The only exception is Harrier, where the shrub and high marsh areas appear to be more stable (TCA=36 and 22; CPLAND= 12 and 7.09 respectively). The meaning of these results is twofold. Although *P. australis* might have the highest edge density it also possesses the highest core area, which means that for the common reed there's enough suitable patches, that it can retire if environmental factors such as changes in salinity, spraying etc. are disadvantageous and spread out again if these factors are favorable. On the other hand for native habitats such as high marsh and low marsh the core areas are significantly smaller leaving these habitats more susceptible for invasion and thus further habitat fragmentation'

Interestingly Perimeter-Area Fractal Dimension (PAFRAC) values are consistent throughout the sites suggesting similar complexity for each assemblage types.

Site	Vegetation	CA (m^2)	NP	PD	TE (m)	ED	PAFRAC	TCA (m^2)	CPLAND (%)	NDCA
Bellemead-Riverside	*SA*	13.28	424	168	27148	107	1.52	13	5.26	424
	PH	81.12	515	204	115533	457	1.47	32	13	309
	PHHMmix	81.40	971	384	158901	629	1.52	24	9.66	488
	HM	43.47	638	253	88699	351	1.49	9.28	3.67	409
	shrub	10.85	47	19	18332	73	1.55	3.07	1.22	75
	upland	5.45	31	12	6628	26	1.39	5.45	2.16	31
Harrier	*PH*	11.01	372	122	29849	98	1.42	2.19	0.72	72
	PHHMmix	13.17	692	227	44666	147	1.47	3.23	1.06	252
	HM	23.20	1210	397	62348	205	1.51	22	7.09	1116
	meadow	3.91	221	73	10423	34	1.50	0.70	0.23	85
	SHPHmix	69.74	786	258	123959	407	1.51	24	7.78	711
	shrub	74.78	897	294	126346	415	1.47	36	12	498
	upland	14.05	317	104	25185	83	1.32	9.94	3.26	232
Hawk	*SA*	10.00	333	236	22110	156	1.56	10	7.08	333
	PH	54.99	152	108	57712	408	1.50	36	25	159
	PHHMmix	8.49	293	207	22693	161	1.52	1.62	1.15	69
	HM	12.43	534	378	34986	248	1.51	2.42	1.71	83
	meadow	5.31	209	148	14306	101	1.51	2.24	1.59	72
	shrub	9.90	146	103	23040	163	1.58	1.86	1.31	43
	upland	15.67	167	118	29920	212	1.49	9.00	6.37	148
Fish Creek	*SA*	9.06	134	118	13811	122	1.51	9.06	7.98	134
	PH	42.26	188	166	40161	354	1.42	27	24	133
	PHHMmix	1.78	79	70	5176	46	1.47	0.21	0.18	10
	HM	24.44	427	376	44072	388	1.46	9.95	8.76	96
	SHHMmix	13.92	335	295	36619	322	1.48	2.06	1.81	80
	upland	1.10	21	18	2525	22	1.48	0.82	0.72	10
Riverbend	*SA*	16.88	816	312	43241	165	1.46	16.88	6.45	816
	PH	110.29	532	203	123954	474	1.45	61	24	298
	PHHMmix	38.71	1402	536	112156	429	1.45	4.69	1.80	309
	HM	77.10	516	197	95211	364	1.45	34	13	306
	upland	0.84	15	6	1298	4.96	1.42	0.84	0.32	15
Secaucus	*SA*	86.11	166	123	22424	166	1.43	83	62	87
	PH	6.79	384	284	24222	179	1.50	4.18	3.09	253
	LMHMmix	3.99	169	125	15521	115	1.62	0.48	0.36	50
	PHHMmix	4.26	455	336	20862	154	1.61	0.14	0.10	24
	HM	9.69	109	81	22473	166	1.61	2.68	1.98	73
	SC	6.37	187	138	19943	147	1.55	6.37	4.71	187

Table 30 Results of Class Level habitat fragmentation metrics at all study sites.

Fragmentation measure codes: CA - Total Area; **NP** - Number of Patches; **PD** - Patch Density; **TE** - Total Edge; **ED** - Edge Density; **PAFRAC** - Perimeter-Area Fractal Dimension; **TCA** - Total Core Area; **CPLAND** - Core Area Percent of Landscape; **NDCA** - Number of Disjunct Core Areas. **Vegetation codes: SA** – *Spartina alterniflora*, **PH –** *Phragmites australis*, **LMHMmix –** low marsh – high marsh mixture, **PHHMmix –** High marsh – *P. australis* mixture, **HM –** high marsh, **SC** – *Spartina cynosuroides*, **SHHMmix –** high marsh – shrub mixture, **SHPHmix –** shrub – *P. australis* mixture.

3.3.4 Results of Landscape Level Metrics

Harrier, Riverbend and Bellemead-Lyndhurst marshes are the largest sites (for mapping purposes Bellemead and Lyndhurst are considered one site). Harrier and Hawk show the greatest Patch Richness with 7, followed by Fish Creek, Riverside, and Secaucus with 6 and Riverbend with 5 (Table 31). Total Core Area (TCA) values show that vegetation assemblages are most clustered at Riverbend (118) and least clustered at Fish Creek (49). Number of Disjunct Core Areas (NDCA) show that beside Riverbend, Harrier and Lyndhurst are the most fragmented landscapes as opposed to Fish Creek, which has the lowest number of DCAD (408). This is mainly due the high *P. australis* intrusion into the high marsh areas at Harrier, Riverbend and Lyndhurst. Diversity index values (SHDI) show that the least diverse site is Secaucus despite displaying more variation is assemblages than Riverbend. This is mainly due to the fact that at the Secaucus site the low and high marshes are the dominant vegetation types covering 86% and 64% of the site respectively, when mud and water are not accounted for. Hawk and Harrier are the most diverse mainly due to the significant presence of upland habitats.

Sites	**TA (m^2)**	**NP**	**TCA (m^2)**	**NDCA**	**DCAD**	**PR**	**SHDI**	**FRAC**
Fish Creek	114	1184	49	463	408	6	1.35	1.46
Harrier	305	4495	98	2966	974	7	1.56	1.45
Hawk	141	1834	63	907	642	7	1.61	1.54
Riverbend	261	3281	118	1744	667	5	1.22	1.44
Riverside	253	2626	87	1736	687	6	1.44	1.49
Secaucus	135	1470	97	674	498	6	0.99	1.52

Table 31 Results of Landscape Level habitat fragmentation metrics at all study sites.
Fragmentation measure codes: TA - Total Area; **NP** - Number of Patches; **TCA** - Total Core Area; **NDCA** – Number of Disjunct Core Areas; **DCAD** - Disjunct Core Area Density, **PR** – Patch Richness; **SHDI** – Shannon Diversity Index; **FRAC**-Fractal Dimension Index

3.3.5 Conclusion of the vegetation classification and habitat fragmentation sections

Selecting indicators of wetland impairment from vegetation classification is straight forward. Area of *P. australis* cover over the rest of the assemblages clearly shows the common reed intrusion to the natural habitats. Percent vegetation cover on the other hand gives a general indication of the overall health of the vegetation, colonization and the effect of inundation.

Summarizing class level and landscape level fragmentation metrics into site specific, discrete indicators is a more delicate task. As the discussion of area, edge and core area metrics presented, all the fragmentation metric values need to be considered together. Discussed alone findings can be misleading. For example seeing large number of patches along with high patch density could be cause of optimism in terms of the connectivity and stability of the habitat. However, when combined with core area metrics, where the assessment shows low number of suitable core areas, the habitat turns out to be highly fragmented and poised to lose even more ground especially if an aggressive invasive species is present in the wetland.

After carefull consideration and literature review the authors propose the following indicators to be used for metrics of habitat fragmentation and spatial distribution: a) percent vegetation cover, b) percent cover of *P. australis,* as well as c) Number of patches, d) percent Phragmites core area, e) high marsh edge/patch area ratio, f) patch richness and g) Shannon diversity index.

Percent vegetation cover is a good surrogate for plant colonization and the general health of the vegetation showing the percentage of the marsh area, where vegetation is established and thriving.

Percent cover of P. australis shows how competitive the native plants are and reflects on the geohydrology of the site as well, given the common reed's aggressive expansion and relative intolerance of high salt concentration.

Number of Patches: total number of patches represents the complexity of the vegetation within the marsh boundaries. In connection with total core area it shows the level of fragmentation in the landscape. A combination of high number of patches and low total core area means highly fragmented habitat, while relatively low number of patches coupled with high total core area measurements means low level fragmentation.

High marsh edge length – patch area ratio (ED/CA): The edge/patch area ratio is an important indicator of levels of fragmentation, the longer the edge of a patch compared to the area, the more the patch is exposed to invasion and fragmentation. Since high marsh habitat is the more susceptible to *Phragmites australis* invasion, the high marsh edge length/patch area ratio was calculated dividing the edge length by the total patch area. The higher this value the more exposed high marsh habitat is to fragmentation.

Percent Phragmites australis core area- Total core area calculates the area of patches big enough to accommodate and support the species. The percent P. australis area gives information on what percentage of the total core area is occupied by P. australis and the . higher this number the greater the level of invasion. ***Patch Richness (PR)*** should be reported along with the diversity index (***SHDI***) to better understand the diversity value. The higher the PR and SHDI value is, the more diverse the marsh vegetation is.

Note that when assigning scores to landscape metrics, class level metrics at each site were taken into consideration as well.

4. Discussion

In this study we compare impartment metrics measured at seven different wetland sites that were selected not randomly but based on their availability for enhancement and acquisition and on a perceived value of the existing plant community. In some cases they are minimally impacted (e.g. River Bend, Hawk Property and Fish Creek) where the natural plant communities survived ditching in the early 1900's, and have experienced the invasion by the common reed but for the most part they have not been affected by excavation, fill or ploughing and remnants of the original low and high marsh communities still exist. Anderson Creek belongs to this same category but has been treated with herbicides to remove *Phragmites* so only hydrological and topographic metrics were measured. The remaining sites have all experienced different levels of transformation, excavation and filling of the marsh surface. Bellemead was a monoculture of common reed before it was restored. The low marsh area was created by grading dredge material from the construction of the NJ turnpike 1993 and the high marsh was mowed and replanted with *Spartina patens* in 1996. Harrier Meadow on the other hand was cut off from full tidal inundation due to the construction of a gas pipeline and the New Jersey Turnpike and after being bermed it was used for rock and soil disposal. Wetland enhancement activities at Harrier Meadow were completed in 1998 and included the excavation of 20 acres of shallow impoundments. Spoils from the excavation were used to create higher elevation areas for suitable nesting and resting habitats. Finally, Secaucus High School Marsh was dominated by a monoculture of common reed before ecological enhancement in 2007 where the common reed was eradicated. The upper 1.5 foot of the marsh surface was completely removed and replaced with an engineered mixed of sand and organic matter. New high marsh areas and channels were created and native brackish marsh vegetation planted. This enhancement resulted in a succession of more or less self-sustaining low and high marsh habitats and lowland scrub-shrub habitats along the marsh/upland edge. Every year there are localized treatments to control common reed invasions.

Secaucus High School Marsh (SHS) received the lowest impairment score (7.37) which makes it the healthiest wetland in the study according to the measured metrics. Secaucus received good scores on most of the vegetation and floristics metrics due to the relatively high percentage of native species and most importantly the high floristic quality of species and low percent cover of the invasive species. Overall 89% of the site is covered by vegetation with mud and bare earth surfaces making up the remaining 11%. Mudflat areas in the low mash area are the reason for low vegetation cover scores. In terms of hydrology the Secaucus site has high hydraulic duty meaning that independent of its area, at high tide, this site holds a large volume of water compared to other sites. This is a desirable attribute since an increase storage capacity may reduce flooding in nearby developed areas. The percent of the site that remains dry at high tide is less than 19%, meaning that the available area for wetlands to retreat under conditions of sea level rise is only one fifth of the site. Moreover, the lowest residence time was measured at this site which would undermine the ability of the wetland to remove excess nutrients from the water column in the form of dissolved inorganic nitrogen. A reason why residence time in this site is short resides in the fact that tidal creeks were dug deeper during enhancement which provides a steeper slope during the ebb phase of the tide. This site was found to be the furthest away from the influence of landfills which is a desirable attribute and one of the closest to sources of sediment. The extent of invasive species core areas from where they can invade adjacent areas is low and the overall number of native species patches is high as desired. On the other hand, the edge to core area ratio is also high meaning long edges between plant community types and consequently more opportunities for invasive species to cross edge zones and colonize new ground. The sites shows a low diversity index (SHDI) which is misleading because of the large low marsh area dominated by the single species *Spartina alterniflora*. When hydrology metrics are not considered the impairment score drops from 7.37 to 6.00.

Hawk Marsh scored second best in the wetland impairment metrics (10). It received bad scores on most of the vegetation metrics mainly because the northern part of the marsh is inhabited by weedy transition and upland areas. The relatively high Shannon diversity index is misleading because it shows high species richness but of species with low floristic quality. Percent *Phragmites australis* cover is close to 50% percent at the site which somewhat subtracts from the higher scores for the percent vegetation cover. The site's hydrology indices are in the middle except for the site specific tidal zone which measures available area for marsh species to retreat under predicted sea level rise conditions. In this case, 62% of the site will be still available for marsh retreat. The hydraulic duty is comparatively low, showing an impaired ability to hold large volumes of water considering the size of the site. The water residence time is in the medium range as well, giving the marsh some ability to remove excess nutrient from the tidal waters. Similarly, the habitat fragmentation metrics in the medium range with relatively low number of patches indicating low level fragmentation and high *Phragmites* core areas suggesting high invasion potential. The high marsh edge/patch ratio is the second lowest indicating, a strong, well established high marsh habitat with relative high species diversity (Table 8). Spatial diversity index and patch richness is excellent. When the hydrology metrics are not accounted for this site receives an 8.50 WIS score.

Riverbend Wetland Preserve scored third best on the impairment scale (10.17). This site has the highest number of native species however the floristic quality is relatively low and the *P. australis* cover is the highest among all the sites. At Riverbend the hydraulic duty is the second highest meaning that – similarly to Secaucus – this site, given its area, can hold large volumes of tidal water compared to other sites. Unlike Secaucus that has deep channels this wetland has shallower channels and hence longer residence time which may improve its ability to remove excess nutrients from the water column while the marsh is inundated. The site specific tidal zone at the site is 72% meaning that only 28% of the marsh surface corresponds to areas where marsh vegetation can effectively retreat from sea level rise. This site is further impaired by being situated right next to Malanka landfill and furthest away from known sediment sources. In terms of fragmentation metrics when all vegetation types are considered the site is slightly impaired due to the high number of patches and unfavorable edge metrics. The high marsh areas show low diversity (mainly *Spartina patens* and *Distichlis spicata)* but have excellent edge/patch ratio and large high marsh core areas. This combination of large core areas and low edge patch ratio contributes significantly to this sites ability to fend off a *Phragmites* invasion. When the hydrology metrics are not counted, the impairment score is significantly lower (8.83).

Fish Creek Marsh received an impairment score of 10.33 with overall good vegetation and floristics metrics by having high plant diversity and species richness as well as being dominated by plants with high floristic quality and having relatively low invasive species cover.

Hydrology metrics are varied. Hydraulic duty is comparatively low which shows a significantly impaired ability for the marsh to hold important amounts of tidal water given its area. On the other hand, water residence time is the longest among all the sites, which means increased likelihood that excess nutrients in the water column would precipitate and remain on the marsh platform and creek bottoms. Fifty six percent of the area of this site is available for marsh species to retreat to given sea level rise and its one of the largest among the sites studied. Habitat fragmentation metrics show a mildly fragmented wetland with strong native vegetation patches and relatively fragmented *P. australis* patches. However, close proximity to landfills and long distance to sediment sources increase the overall impairment score. When hydrology metrics are not accounted for, this site scores the second lowest (7.83).

Harrier Meadow obtained the second worst impairment metric score (10.67). Enhancements at this site have improved its biodiversity and floristic quality yet vegetation and floristics metrics remain somewhat impaired due to the high percent of invasive species in both the upland and high marsh areas. Although floristic quality of the native species is high, they are significantly impacted by the invasive *P. australis*. Close proximity to landfills and highly fragmented native habitats further impair the site. High number of vegetation patches and high marsh edge/patch ratio indicates highly fragmented native habitats and vulnerability to *P. australis* invasion which is further enhanced by large core areas of this species. The wetland is situated close to the One-E ladnfill and its large and convoluted distance to sediment sources results in less than ideal metrics for these two categories. It must be noted, that water flows to and from the site are restricted by culverts and so no hydraulic measurements were made or hydraulic metrics calculated. Not counting hydrology impairments, Harrier is the most impaired site with the impairment score of 10.67.

The ecologically most impaired sites are the adjacent marshes of **Bellemead and Riverside** (impairments score of 11.97). Overall the vegetation metrics are not good. A low Shannon diversity value indicates low diversity and low species richness and the floristic quality is low due to the dominant cover of invasive species. The hydraulic duty is small which means that the site can hold less water at high tide compared to other sites. The low water residence indicates less time for nutrients in the water column to drop out onto the marsh surface and creek bottoms. These two contiguous sites are close to sediment sources which is a desirable attribute. However, their closeness to landfills further contributes to a higher impairment score. Native habitats of low and high marsh are scarce and highly fragmented with a high edge/patch ratio specially for the high marsh remnants. Relatively high cover of *P. australis*-high marsh mixture shows some resiliency on part of the high marsh to persist and if indeed these sites are considered for ecological enhancement, their high marsh areas should be high priority targets. When hydrology metrics are not considered, together Bellmead and Riverside score second to last with and impairment score of 9.33.

Metrics	Impairment indicators	RS	FC	HM	HP	RB	SHS
Vegetation and floristics	**Native Mean**	3.40	4.80	3.60	3.40	6.30	5.80
	Rank ordered	**0.67**	**0.50**	**1.00**	**0.67**	**0.17**	**0.33**
	Total Mean	2.60	3.70	2.30	2.00	5.50	4.90
	Rank ordered	**0.67**	**0.50**	**0.83**	**1.00**	**0.17**	**0.33**
	Floristic Quality	15.70	20.30	18.20	16.50	16.60	19.30
	Rank ordered	**1.00**	**0.17**	**0.50**	**0.83**	**0.67**	**0.33**
	Plant Stewardship Index	11.80	15.90	11.70	9.50	14.60	16.30
	Rank ordered	**0.67**	**0.33**	**0.83**	**1.00**	**0.50**	**0.17**
	Shannon-Wiener Div. Index	1.68	1.82	1.80	2.12	1.68	1.96
	Rank ordered	**0.83**	**0.5**	**0.67**	**0.17**	**0.83**	**0.33**
	Percent plant cover	0.90	0.80	0.74	0.83	0.90	0.89
	Rank ordered	**0.17**	**0.83**	**1.00**	**0.67**	**0.17**	**0.50**
	Percent invasive species cover	0.48	0.38	0.17	0.42	0.50	0.07
	Rank ordered	**0.83**	**0.50**	**0.33**	**0.67**	**1.00**	**0.17**
Hydrology	**Tidal asymmetry index**	2.53	2.09	N/A	1.50	1.13	0.77
	Rank ordered	**1.00**	**0.80**	**0.00**	**0.60**	**0.40**	**0.20**
	Hydraulic duty	0.07	0.03	N/A	0.07	0.10	0.20
	Rank ordered	**0.50**	**0.83**	**0.00**	**0.50**	**0.33**	**0.17**
	Water residence time	0.67	3.2	N/A	1.61	1.12	0.59
	Rank ordered	**0.80**	**0.20**	**0.00**	**0.40**	**0.60**	**1.00**
	Area of Site specific Tidal Zones	0.54	0.44	0.61	0.38	0.72	0.81
	Rank ordered	**0.50**	**0.33**	**0.67**	**0.17**	**0.83**	**1.00**
Habitat fragmentation	**Distance From Sediment Source**	27727	44715	41773	34299	40559	13073
	Rank Ordered	**0.33**	**1.00**	**0.83**	**0.50**	**0.67**	**0.17**
	Number of Patches	2626	1184	4495	1834	3281	1470
	Rank Ordered	**0.67**	**0.17**	**1.00**	**0.50**	**0.83**	**0.33**
	High marsh ED/CA:	2.04	2.69	2.82	1.80	1.23	2.32
	Rank Ordered	0.50	0.83	1.00	0.33	0.17	0.67
	Percent Phragmites Core Area	64	30	60	55	56	4
	Rank Ordered	**1.00**	**0.33**	**0.83**	**0.50**	**0.67**	**0.17**
	Patch Richness	6.00	6.00	7.00	7.00	5.00	6.00
	Rank Ordered	**0.50**	**0.50**	**0.17**	**0.17**	**1.00**	**0.50**
	Shannon Diversity Index	1.44	1.35	1.56	1.61	1.22	0.99
	Rank Ordered	**0.50**	**0.67**	**0.33**	**0.17**	**0.83**	**1.00**
	Distance from landfills	121437	156376	118385	125454	140626	270946
	Rank Ordered	**0.33**	**1.00**	**0.83**	**0.67**	**0.50**	**0.17**
Wetland Impairment Score		**11.13**	**10.33**	**10.67***	**10.00**	**10.17**	**7.37**

Table 32 Wetland Impairment Score

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