


The Equal Importance of Rapid and Intensive Metrics for Coastal Wetland Reference Standards in New Jersey

Bridging Methodological Gaps for Evaluating Coastal Marsh Restoration Performance

Mid Atlantic Coastal Wetlands Assessment

Report

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MACWA

Mid-Atlantic Coastal Wetlands Assessment

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More information on MACWA can be found on the Partnership for the Delaware Estuary's MACWA page: http://www.delawareestuary.org/science-and-research/wetlands/macwa-homepage/.

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Introduction

Tidal marshes in the Mid Atlantic have a long legacy of anthropogenic disturbance due to their abundant resources and position along major waterways used in colonial commerce (Kirwan et al. 2011; Mudd 2011). Disturbances and manipulations varied by the century, where practices ranged from diking for crop cultivation in the 1800's, to ditching for mosquito control in the 1930's, and, most recently, waterfront secondary residence construction in the 1950's (Ferrigno 1976; Smith et al. 2016; Kirwan et al. 2011; Mudd 2011). These historical manipulations have fabricated a mosaic of different conditions across tidal marsh landscapes.

Regardless of the legacy of manipulation, each tidal marsh is integral to the defense of our coastlines against a changing climate (Arkema et al. 2013; Sutton-Grier et al. 2015; Narayan et al. 2017). Unfortunately, the prognosis of heavily impacted tidal marshes under a regime of rising sea levels is poor, but within the last decade, restoration efforts to sustain tidal marsh acreage to protect coastal assets have escalated. Strategies to choose candidate tidal marshes for restoration, however, are inconsistent. Further, there are information gaps between how tidal marsh condition is related to marsh response, or function, to sea level rise (Box 1).

There are currently few reference standards for tidal marsh conditions in New Jersey or the surrounding region, which makes assessing the appropriateness of sites for restoration inherently difficult. Restoration practitioners need a systematic way to categorize tidal marsh condition to better prioritize actions.

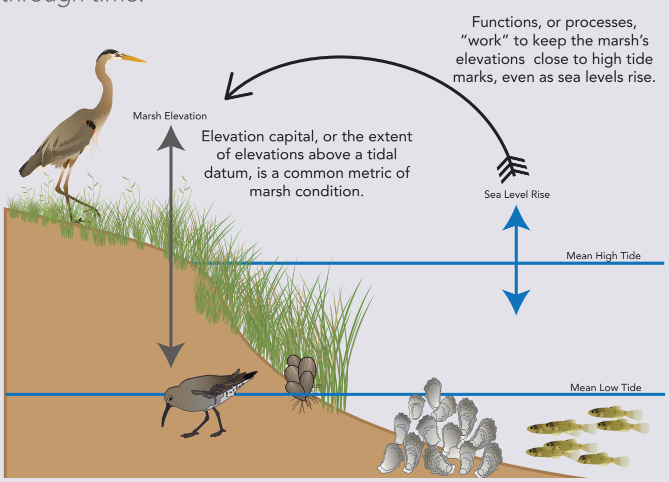
Data streams used in this study are part of the Mid Atlantic Coastal Wetlands Assessment (MACWA), a multi-tier EPA approved wetland monitoring program (Figure 1). MACWA supports coordinated and consistent efforts to assess coastal wetlands across the Mid Atlantic (for more information see previously released reports). The MACWA's watershed-wide condition assessments (Tier 2) are carried out using the Mid Atlantic Tidal Rapid Assessment (MidTRAM) protocol. MidTRAM uses habitat, hydrology, and landscape buffers attributes, measured on the ground, to categorized overall wetland condition by intensity of stress. Long term monitoring, or Tier 4, of the MACWA program is implemented through Site Specific Intensive Monitoring (SSIM).

Box 1: What is the difference between tidal marsh *condition* and *function*?

Condition Condition refers to the state of an ecological system[1]. Descriptions of a particular state include their physical, chemical, and biological characteristics; specific processes or interactions that connect certain characteristics also help define conditions. "Robust," "poor," "stressed," or simply "good" or "bad," are common words to describe a particular condition.

Function Functions are state changes through time or the interactions that result in those changes[2]. Functions, also referred to processes, are cause-effect relationships or pathways.

Tidal marshes naturally respond to perturbations. In order to do so, they need ample sediment and healthy plant growth. They depend on cyclical, well timed inundation. Altering any of these factors can disrupt the ambient rate of recovery from a particular perturbation. State of recovery are the tidal marsh's condition, which is a point in time. The process of recovering can be attributed to certain marsh functions *through* time.



1. https://www.epa.gov/report-environment/ecological-condition 2. https://esanalysis.colmex.mx/Sorted%20Papers/2005/2005%20DEU%20-3F%20Phys.pdf

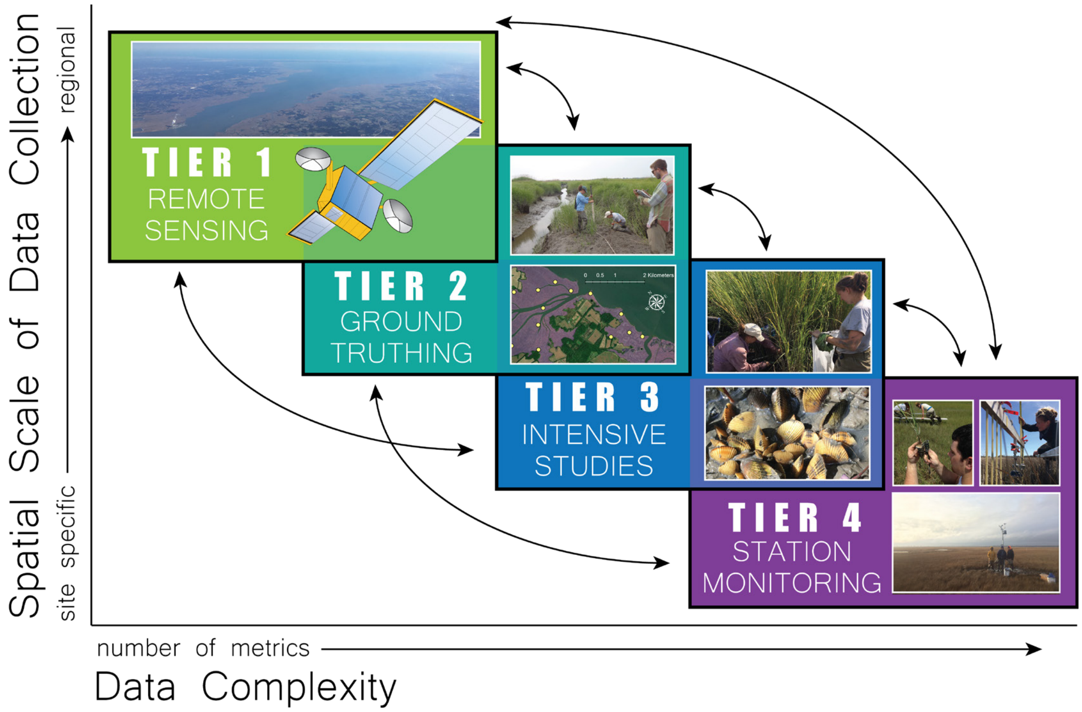


Figure 1. The MACWA program was designed to include four monitoring tiers: 1) remote sensing, 2) ground truthing, 3) intensive studies, and 4) station monitoring.

SSIM objectives seek to answer questions about site-specific temporal variability in coastal wetland metrics considered important to their resilience to sea level rise, and other local stressors. Long term datasets elucidate functional processes. Each SSIM station is based around 3 surface elevation tables and marker horizon arrays (SET-MHs), coupled with soil, water, and plant productivity (e.g. biomass) sampling methods.

To help resolve information gaps regarding the relationships between condition and function, we assessed the condition of seven long term monitoring locations using rapid assessment methods. Since 2010, more than 10 watersheds (over 300 points) have been assessed using the MidTRAM technique across New Jersey, Delaware, and Pennsylvania. These studies have been used to inventory stressors, find spatial variability in condition, and compare the different types of stressors within similar watersheds. Likewise, more than six years of long term monitoring data is available at eleven annually monitored long term sites. Those data provide insights into the spatial and temporal variability of plant production, sedimentation, and water conditions. To date, however, no studies have sought to categorize the relative condition of each salt marsh SET-MH in New Jersey. Long term monitoring data are essential for understanding geomorphic dynamics and planning restoration projects using quantitative data, yet it is equally important to know how those quantitative data compare to local conditions. For instance, are those data representative of a location that has been deemed more vulnerable to sea level rise? Are those data from a site that is very stressed? Do they represent a high quality site?

This report seeks to investigate three questions to build information about appropriate salt marsh reference conditions in New Jersey using existing methods and conventions: 1) What is the condition of each SET-MH site relative to other watershed-wide condition scores? 2) Do intensive methods correlate with rapid methods for productivity? 3) Does condition correlate with vulnerability to sea level rise, with respect to elevation changes? The data used in this study are a combination of previous watershed-wide condition assessments, long term data, and new field condition assessments at long term monitoring sites.

Methods

Study Sites

Monitoring Stations of the Bayshore

Expansive tracts of tidal salt marsh border the Delaware Bay, an area known as the Bayshore (Figure 3B). These marshes are meso- or polyhaline (11-20‰). They are typically dominated by *Spartina alterniflora, Spartina patens,* and *Distichlis spicata*. Tidal ranges are approximately 1.6-1.9 m. Monitoring stations, from west to east, include: Dividing Creek (NJ), Maurice River (NJ), Dennis Creek (NJ). Dividing Creek is located in Cumberland County, NJ. It drains into the Bay to the southeast of Fortescue, NJ. The Maurice River study site, also in southern Cumberland County, is just upstream of Matts Landing, in Heislerville, NJ. Dennis Creek is located in northwest Cape May County, NJ. Six to eight years of long term monitoring has been conducted at these three sites.

Monitoring Stations of the Barnegat Bay

Barnegat Bay, a microtidal lagoon, separates New Jersey from the Atlantic Ocean by a barrier island (Figure 3A). Salt marshes in the Barnegat Bay are polyhaline (>19‰) and are dominated by *Spartina alterniflora*, *Spartina patens*, and *Distichlis spicata*. Tidal ranges are generally < 0.7 m. Monitoring stations from north

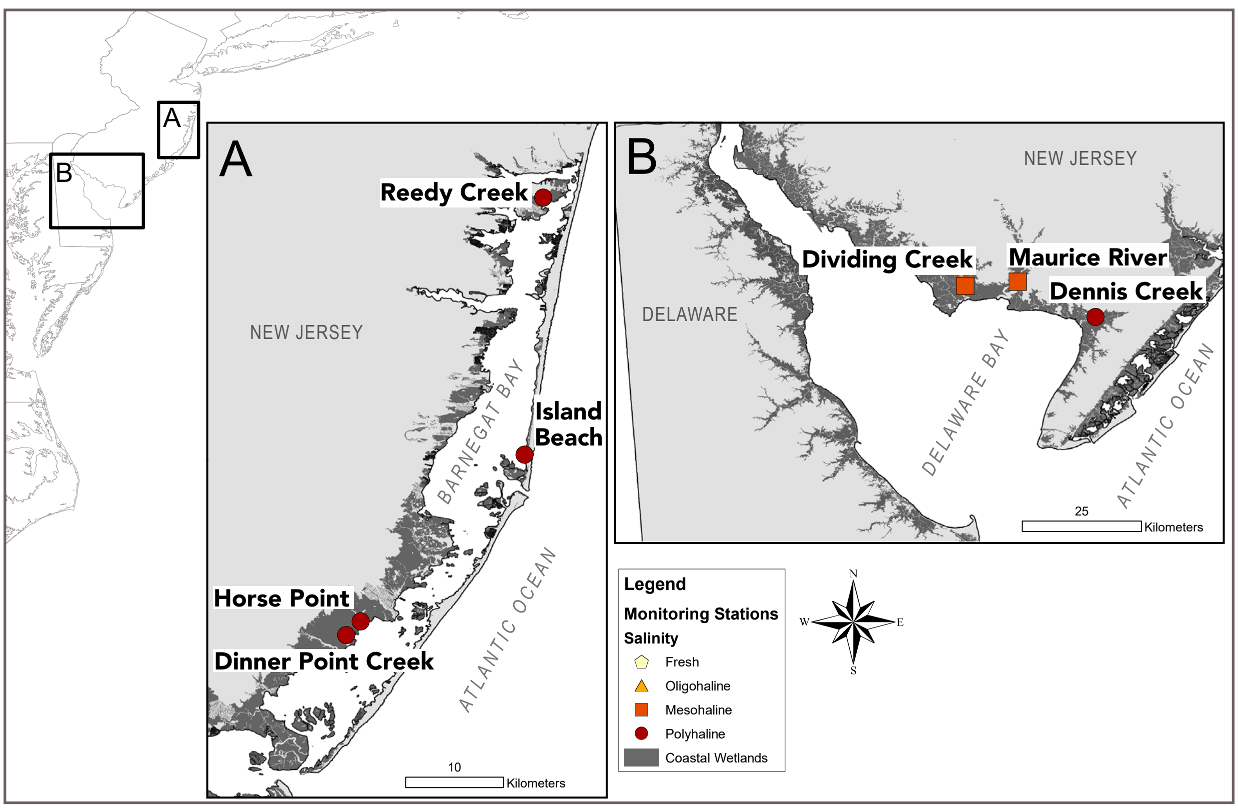


Figure 2. In the Mid Atlantic, the primary two study estuaries in this report are the Barnegat Bay (A) and the Delaware Estuary (B). Barnegat Bay sites were, from north to south: Reedy Creek, Island Beach State Park, Horse Point, and Dinner Point Creek. In the Delaware Estuary, sites were, from west to east: Dividing Creek, Maurice River, and Dennis Creek.

to south, include: Reedy Creek, Island Beach State Park, Horse Point, and Dinner Point Creek. Reedy Creek is in northern Barnegat Bay. It is part of the Edwin B. Forsythe National Wildlife Refuge (EBFNWR). Island Beach State Park (IBSP) forms the north shore of the Barnegat Bay Inlet. The study site is on the backside of backside of the barrier island. Horse Point and Dinner Point Creek are located in southern Barnegat Bay within the EBFNWR. Horse Point was established as a comparative site for the Dinner Point Creek site after mosquito management activities placed sediments on the existing surface elevation tables. Six to seven years of long term monitoring has been conducted at these four sites.

Site Specific Intensive Monitoring

Each SSIM station has 3 surface elevation tables (SET) each coupled with 3 marker horizon plots (MH) each to discern surface accretion (Lynch et al. 2015; each unit of 1 SET with 3 MHs is referred to as a "SET-MH"). SET-MHs have been read 1-3 times per year, since approximately 2010-2012. Trends from SET-MH were derived using linear regressions, as described by Lynch et al. (2015). All available biomass data were averaged across years per site. Biomass was sampled in the general vicinity of SETs 1 and 3, for the first 3-4 years at each site, to accommodate annual variability. Biomass, a proxy for plant production, consisted of both above and below ground sample collection. Other metrics collected at SSIM stations, but not used in this study, included: real time kinematic (RTK) elevation surveys, water quality data, and soil quality. More information about data collection and quality can be found in related SSIM QAPPs and reports (Box 2).

Box 2: Site Specific Intensive Monitoring - Reports and Quality Assurance Objectives

Details on metrics and data collection methodologies are furnished through the SSIM Quality Assurance Project Plans (<http://www.delawareestuary.org/science-and-research/wetlands/macwa-homepage/macwa-supportingdocs/>).

Previous SSIM reports: <http://www.delawareestuary.org/science-and-research/wetlands/wetlands-data-reports/>

Rapid Assessment Methods

For watershed wide rapid assessments, we followed the protocols outlined in Mid-TRAM (or simply RAM) version 3.0 and 4.0, depending on the year assessments were conducted (Box 3). Watershed wide assessments uses 30 randomly placed 50 m^2 assessment areas (AAs) in tidal marsh habitat within a designated watershed (HUC 12-14). Each assessment area is surveyed using hydrological, habitat, and landscape attributes. Each attribute is composed of several quantitative or qualitative metrics. Buffer metrics consider stressor or landward migration impediments within 250 meters of each AA. Hydrological metrics are observations of anthropogenic changes to the hydrology of the AA including ditching, fill, or diking. Habitat metrics capture plant community composition, substrate firmness, and invasive plant cover, which are proxies for structural complexity and ecological function.

Box 3: Mid Atlantic Tidal Rapid Assessment Method - Reports and Quality Assurance Objectives

Details on metrics and data collection methodologies are furnished through the MidTRAM Quality Assurance Project Plans (<http://www.delawareestuary.org/science-and-research/wetlands/macwa-homepage/macwa-supportingdocs/>).

MidTRAM v4.1 Protocols: <http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Documents/MidTRAM%20V4.1%20FINAL.pdf>

Previous MidTRAM reports: <http://www.delawareestuary.org/science-and-research/wetlands/wetlands-data-reports/>

Attributes are averaged to compute a final score. Final scores are used to categorize each site as minimally (final scores of >81), moderately (61-81), or severely stressed (<61). Data from assessments in Maurice and Dennis (2010, 2014 respectively) were used to compare SET-MHs in Delaware Bay. We surveyed 2 additional AAs in Dividing to provide more data for the Dividing watershed. RAM assessments from Northern and Souther Barnegat Bay (2012-2013) were used to compare SET-MHs in Barnegat Bay.

Rapid Assessments at Monitoring Stations

In the summers of 2016 and 2017 MidTRAM (v4.0) was performed at SET-MHs. A total of 21 AAs were used to study RAM in the vacintiy of SSIM comparability and gauge relative condition at each SET-MH. Unlike typical RAM assessments, SET-MHs points were non-randomly located. Additionally, MidTRAM transects were established around the footprint of the SET (Figure 2). to create consistency as well as to avoid damage to the SET-MH area. Attribute and final scores were used to categorize each SET-MH as minimally (final scores of >81), moderately (61-81), or severely stressed (<61). The conditions of each SET-MH relative to watershed-wide assessments were discerned by graphing all condition scores along a cumulative distribution function.

Box 4: RAM at SSIM - Quality Assurance Objectives

For more details on this study, see this project's Quality Assurance Project Plan (<http://www.delawareestuary.org/science-and-research/wetlands/macwa-homepage/macwa-supportingdocs/>).

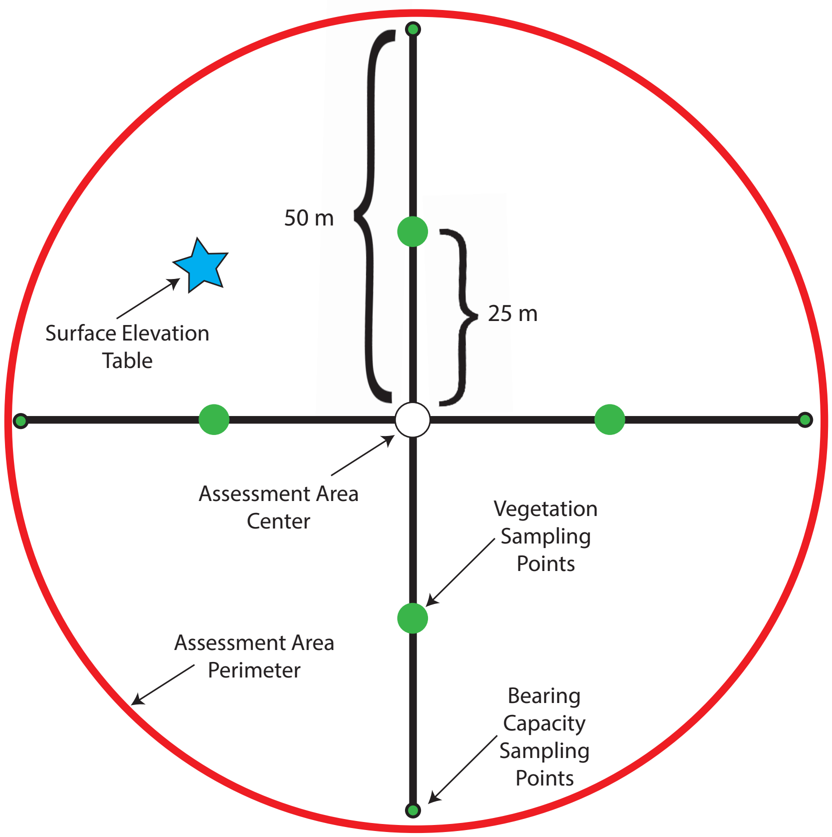


Figure 3. Assessment area layout used to perform rapid assessment methods at each SET. Over the years, biomass samples for long term monitoring were collected within the quadrant of the assessment area containing the SET.

Synthesis

All metrics were correlated using linear models to test comparability between SSIM and RAM methodologies. Correlation coefficients (*R*) greater than ±0.4 were considered strong. Select relationships were chosen to graph. Linear model fit (*p* and R^2 values) for these selected comparisons were used to discern the variability of each relationship.

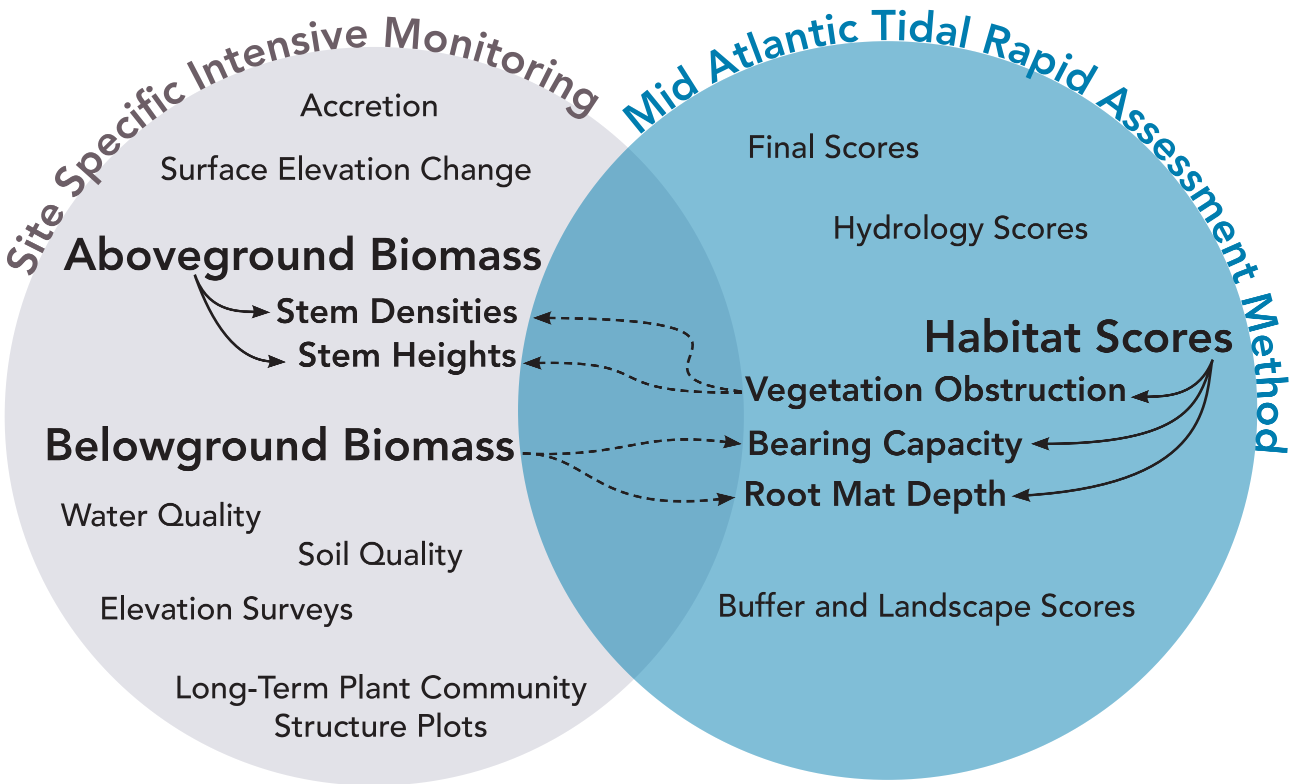


Figure 4. Venn diagram of metric similarities between Site Specific Intensive Monitoring and Mid Atlantic Tidal Rapid Assessments. The solid, black arrows are submetrics of the metric of origin, whereas dotted, black arrows connect comparative quantitative metrics.

Results

SSIM

Changes in elevation from SETs ranged from 0.74 to 6.9 mm·yr^{-1} along the Bayshore and -1.97 to 5.77 mm·yr^{-1} in Barnegat Bay (Table 1). Accretion rates along the Bayshore ranged from 3.72 to 10.1 mm·yr^{-1} along the Bayshore, and 1.91 to 5.87 mm·yr^{-1} in Barnegat. As a means to compare how elevations are changing with respect to sea level rise, elevation changes from each SET-MH were subtracted from local rates of sea level, which were 4.5 and 4.1 mm·yr^{-1} for the Bayshore and Barnegat Bay, respectively. This value is referred to as the accumulation deficit, because lower values suggest that sea level is rising more rapidly the elevations are accumulating. Accumulation deficits ranged from -3.76 to +2.40 in the Bayshore, and -6.07 to +1.67 in Barnegat. Above ground biomass ranged from 489 to 923 g·m^{-2} in the Bayshore and 98 to 1,211 g·m^{-2} in Barnegat Bay. Stem density and stem heights, respectively, ranged from 484 to 4,743 stems·m^{-2} and 33 to 54 cm in the Bayshore and 915 to 4,541 stems·m^{-2} and 17 to 32 cm in Barnegat Bay. Below ground biomass ranged from 3,886 to 5,679 g·m^{-2} in the Bayshore and 4,280 to 10,608 g·m^{-2} in Barnegat Bay.

RAM at SSIM

In 2016 and 2017 MidTRAM (v4.0) was performed at 12 SET-MHs in Barnegat Bay and 9 in the Bayshore. These assessments yielded final scores ranging from 73 to 87 in the Bayshore, and 74 to 86 in Barnegat (Table 1). Buffer attribute scores ranged from 73 to 100 in the Bayshore, and 80 to 93 in Barnegat. Hydrological scores in the Bayshore ranged from 75 to 100, whereas in Barnegat the range was 75 to 100. Habitat scores ranged from 40 to 60 in the Bayshore, and 47 to 73 in Barnegat. Submetrics of Habitat scores included root mat depth, bearing capacity, and vegetation obstruction. For the Bayshore, these metrics ranged from -35 to -17 for root mat depths, -7.44 to -3.03 for bearing capacity, and 38 to 64% for vegetation obstruction. For Barnegat, these metrics ranged from -67 to -30 for root mat depths, -6.66 to -1.53 for bearing capacity, and 0.5 to 50% for vegetation obstruction.

Scores were ranked from lowest to highest scores for the Bayshore and Barnegat watershed wide dataset, where lowest scores were ranked the lowest, starting with 1, and ending with 79 in the Bayshore and 73 Barnegat (Table 1 and Figure 5). As such, ranks of SET-MH AAs ranged from 15 to 67 in the Bayshore and 41 to 69 in Barnegat; the median score for Bayshore was 27 but 55 for Barnegat.

Severely, moderately, and minimally stressed sites, respectively, accounted for 11%, 39%, and 49% of the total RAM dataset in the Bayshore (Figure 5A). SET-MHs along the Bayshore, however, were in moderate condition compared to the larger RAM dataset. Dennis Creek SET 2, however, is in particularly good condition.

In Barnegat, percentages of the population for severely, moderately, and minimally stressed were 26%, 56%, and 20% (Figure 5B). Most of Barnegat's SET-MHs were minimally stressed as a large proportion of the entire RAM dataset had lower scores than these SET-MHs.

Synthesis

Correlation results (*n*= 56 separate tests) showed 23% of those relationships correlated greater than R±0.4 (Table 2; Figures 6-10). Root mat depths correlated with accretion and blade heights from above ground biomass samples, but neither correlation produced strong linear models (i.e. $p<0.05$, $R^2>0.4$)(Figure 6).

Hydrology scores correlated with total above and below ground biomass; these correlations produced linear trends (p=0.02), but R^2 values were moderate (R^2=0.35; Figure 7). Habitat scores correlated well with stem densities, stem heights, and below ground biomass (all had R^2>0.4)(Figure 8). Habitat scores and stem densities produced a slightly significant linear trend (p=0.07) with a weak fit (R^2=0.24). Stem heights and below ground biomass correlations with Habitat score had significant linear models (p-values were <0.01), with good fits (R^2 values were >0.5). Vegetation obstruction correlated with blade heights very well and produced a significant linear model (p=0.0091), with good fit (R^2=0.45)(Figure 9). Bearing capacity correlated well with below ground biomass and produced a significant linear model (p=0.00057), with a good fit (R^2=0.64)(Figure 10).

Of the RAM-SSIM metrics that were correlated, those related to above or below ground biomass were most notable. Our ability to correlate rapid field methods, such as bearing capacity, to more intensive inventories of below ground biomass may prove useful for future mapping efforts involving tidal marsh carbon stocks. The same would be true for relationships between vegetation obstruction, the rapid field method, and blade heights from above ground biomass sampling.

Although relatively weak compared to the other relationships we observed, root mat depths correlated with accretion and plant blade heights. These relationships are intuitive in the context of tidal marsh hydrology, where more inundation leads to taller plants with less root mat and higher accretion rates. Interestingly hydrology scores were also correlated with biomass, which supports the notion that inundation, and things like ditching or diking, have significant impacts to plant production.

Lastly, final condition scores and accumulation deficits relative to sea level rise were not correlated (p=0.348, R^2=0.049; Figure 11). Lower Final Scores had a large range of values for accumulation deficits (-6 to +2 $mm \cdot yr^{-1}$), whereas high Final Scores had a narrow range of slightly more positive accumulation deficits (range of ~0 to +2 $mm \cdot yr^{-1}$). There was no pattern between final scores, accumulation deficits, and location. This suggests that these values were not biased by geography alone. It is important to note that not all condition metrics are indicative of long term elevation changes, especially as elevation changes are just one aspect of vulnerability to tidal marsh loss. Holistic condition accounts for many other factors, such as landscape level stressors and so the lack of direct correlation between condition score and elevation change rates are not all together surprising. Odds are, however, that tidal marshes with lower condition scores will not fare particularly well with sea level rise, climate change, or any other factors which may change through time.

Table 1. Tabular results for SSIM long term monitoring metrics and RAM at SSIM assessments.

Location Labels	SSIM Metrics							RAM Metrics							
				Above Ground Biomass Metric						Habitat Attribute					
	Elevation Change Rate ($mm \cdot yr^{-1}$)	Accretion Rate ($mm \cdot yr^{-1}$)	Accumulation Deficit ($mm \cdot yr^{-1}$)	Total Biomass ($g \cdot m^{-2}$)	Stem Density ($\# \cdot m^{-2}$)	Weighted Stem Heights (cm)	Below Ground Biomass ($g \cdot m^{-2}$)	Buffer Score	Hydrology Score	Habitat Score	Root Mat Depth (cm)	Bearing Capacity (cm)	Vegetation Obstruction (%)	Final Score	Watershed-wide Rank
Bayshore															
DIV 1	5.86	8.17	1.36	696	4743	33	4603	87	75	60	-30	-3.66	38	74	20
DIV 2	0.74	10.1	-3.76	-	-	-	-	100	100	40	-20	-7.06	64	80	39
DIV 3	1.47	6.01	-3.03	619	1401	41	5118	93	92	60	-	-3.13	52	82	42
MAU 1	1.17	7.70	-3.33	926	668	54	3886	93	100	47	-27	-7.44	62	80	34
MAU 2	3.78	3.72	-0.72	-	-	-	-	93	100	40	-32	-6.80	53	78	26
MAU 3	5.22	6.82	0.72	733	484	45	4389	93	100	40	-30	-4.53	38	78	27
DEN 1	5.14	7.00	0.64	489	1387	38	6739	93	83	53	-17	-5.81	55	77	24
DEN 2	6.29	3.79	1.79	-	-	-	-	100	100	60	-30	-3.03	53	87	67
DEN 3	6.90	5.06	2.40	655	964	43	5679	73	92	53	-35	-5.78	63	73	15
Barnegat Bay															
RDY 1	5.22	4.76	1.12	534	1079	30	4905	87	92	47	-39	-6.66	33	75	44
RDY 2	5.77	6.72	1.67	-	-	-	-	87	92	73	-60	-3.56	40	84	64
RDY 3	2.24	4.52	-1.86	1211	4541	30	4280	93	100	60	-42	-5.97	25	84	67
IBSP 1	0.63	2.91	-3.47	98	915	21	9786	93	75	60	-35	-1.78	33	76	48
IBSP 2	-1.97	3.63	-6.07	-	-	-	-	93	75	53	-67	-2.53	17	74	41
IBSP 3	1.33	2.57	-2.77	559	1786	23	9307	93	75	60	-57	-1.59	50	76	49
HP 1	3.92	5.87	-0.18	936	1662	16	10322	93	92	73	-40	-2.19	33	86	68
HP 2	4.40	5.87	0.30	-	-	-	-	93	92	60	-33	-1.75	38	82	62
HP 3	4.18	5.39	0.08	460	2172	17	8145	93	92	73	-30	-1.53	34	86	69
WC 1	*	*	*	628	3167	22	10608	87	75	67	-35	-2.22	35	76	50
WC 2	0.30	6.07	-3.80	-	-	-	-	80	75	67	-40	-2.75	34	74	42
WC 3	5.52	1.91	1.42	538	4027	32	10068	87	92	67	-40	-1.84	0.50	82	61

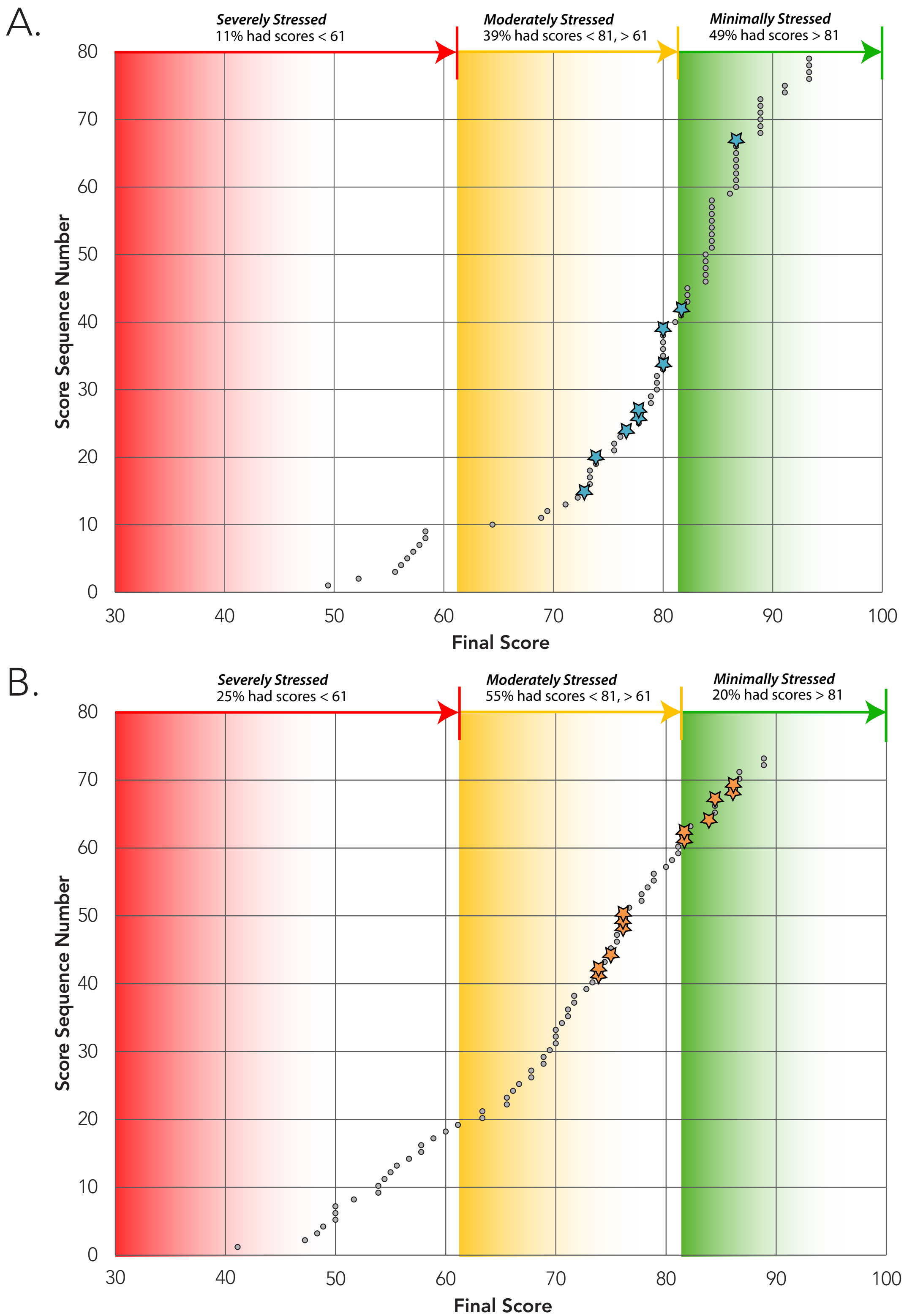


Figure 5. Cumulative distribution of watershed-wide RAM scores in the Delaware Estuary (A, n=79) and Barnegat Bay (B, n=73). RAM at SSIM sites are marked with a star: blue for the Delaware Estuary (A) and orange for Barnegat Bay (B). Condition breakpoints were severely (red), moderately (yellow), and minimally (green) stressed.

Table 2. Tabular results of correlations (*R*) between SSIM (column headers) and RAM (row labels) metrics. Metrics for SSIM consist of: SET cumulative elevation rate (ElevCR), marker horizon accretion rate (Acc), accumulation deficit relative to SLR (Acc.def), above ground biomass (Agbio), stem density (Stemden), weight mean stem height (StemH), and belowground biomass (Bgbio). Metrics for RAM included: qualitative disturbance rating (QDR), Buffer Score (Buff), Hydrology Score (Hydro), root mat depth (RM D), bearing capacity (BC), vegetation canopy density (V_dens), Final Score (Final), and Habitat Score (Hab).

	ElvCR	Acc	Acc.def	Agbio	Stemden	StemH	Bgbio
QDR	−0.0585	−0.173	−0.0275	−0.222	0.301	−0.245	0.0763
Buff	−0.293	0.084	−0.308	0.0617	−0.0872	−0.191	0.0589
Hydro	0.348	0.225	0.323	**0.589**	−0.205	**0.493**	**−0.535**
RM D	0.317	**0.486**	0.27	−0.111	−0.191	**0.438**	−0.348
BC	−0.0855	**−0.453**	−0.039	**−0.446**	0.235	**−0.725**	**0.801**
V_dens	0.268	0.269	0.214	−0.0854	−0.373	**0.668**	−0.177
Final	0.117	−0.244	0.17	−0.0721	**0.494**	**−0.771**	**0.712**
Hab	0.205	0.00666	0.221	0.398	0.178	−0.293	0.163

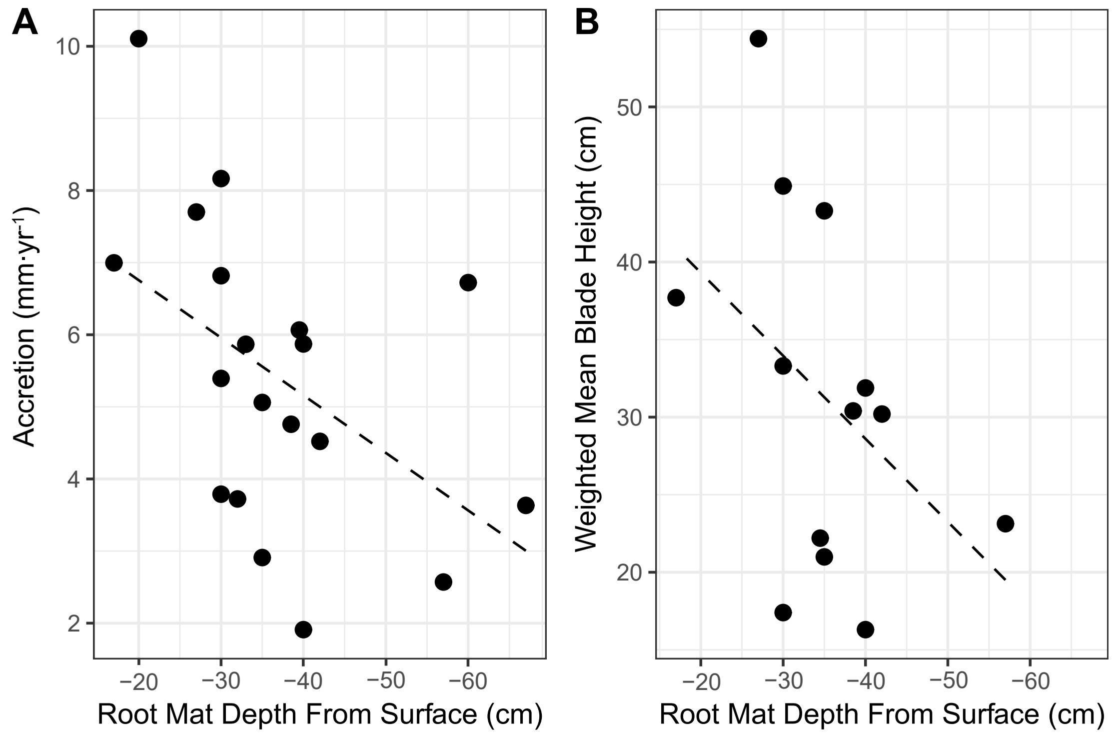


Figure 6. Correlation of Root Mat Depth (RAM) to SSIM metrics: accretion (A)(R=0.48; p=0.035; R^2=0.24) and weighted mean blade heights (B)(R=0.43; p=0.13; R^2=0.19).

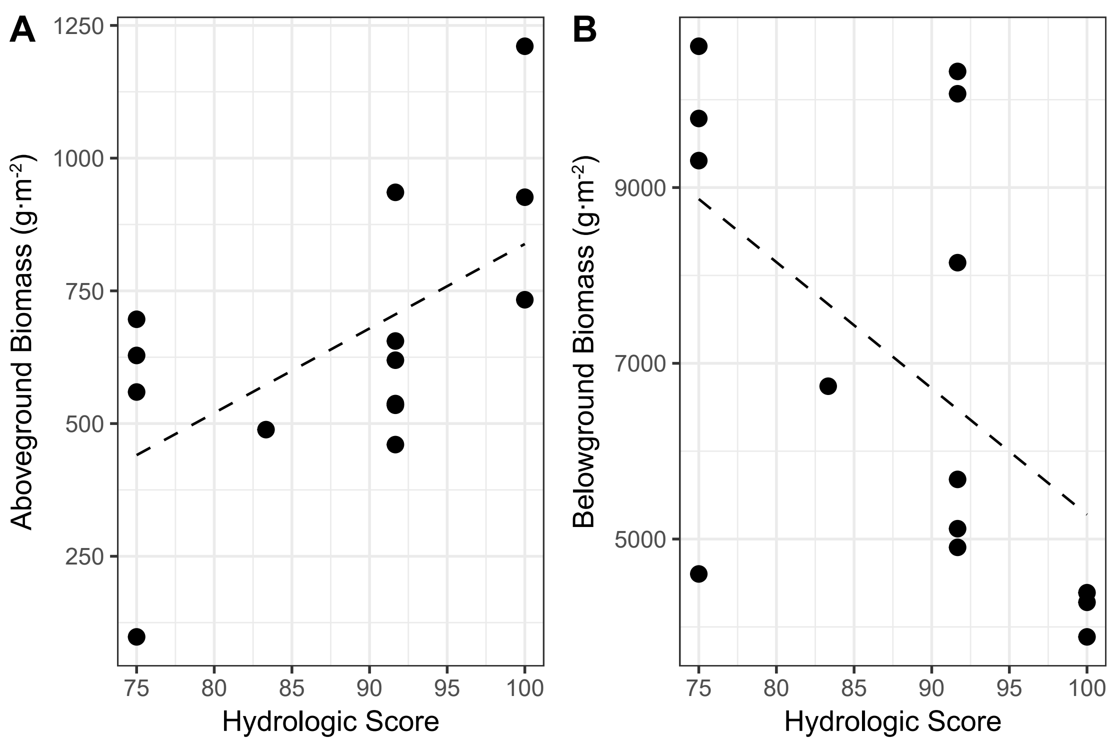


Figure 7. Correlation of Hydrology Score (RAM) to SSIM metrics: above ground biomass (A)(R=0.59; p=0.02; R^2=0.35) and below ground biomass (B)(R=-0.54; p=0.05; R^2=0.29).

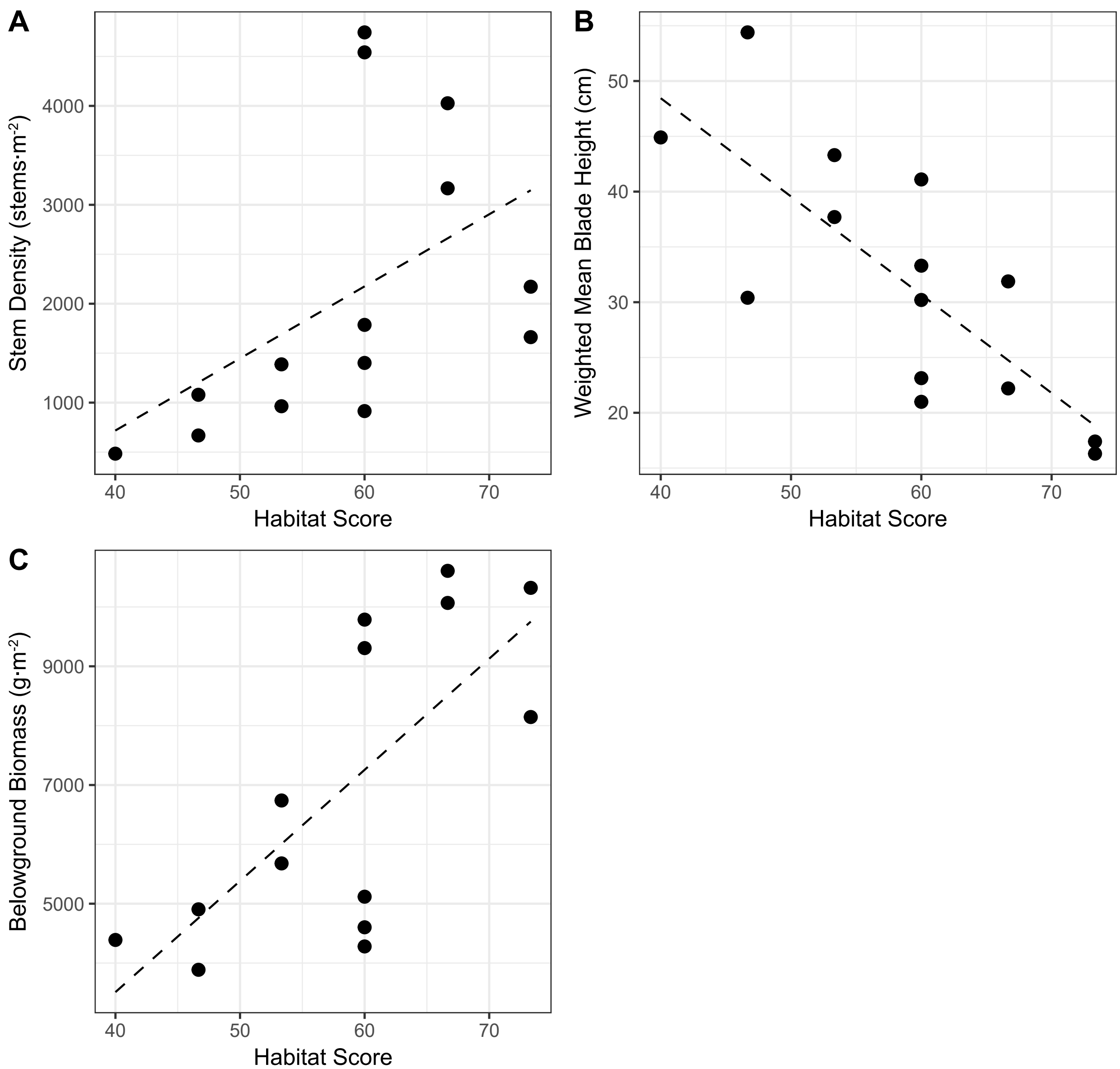


Figure 8. Correlation of Habitat Score (RAM) to SSIM metrics: stem density (A)(R=0.49; p=0.07; R^2=0.24), weighted mean blade height (B)(R=-0.77; p=0.0012; R^2=0.59), and below ground biomass (C)(R=0.71; p=0.004; R^2=0.51).

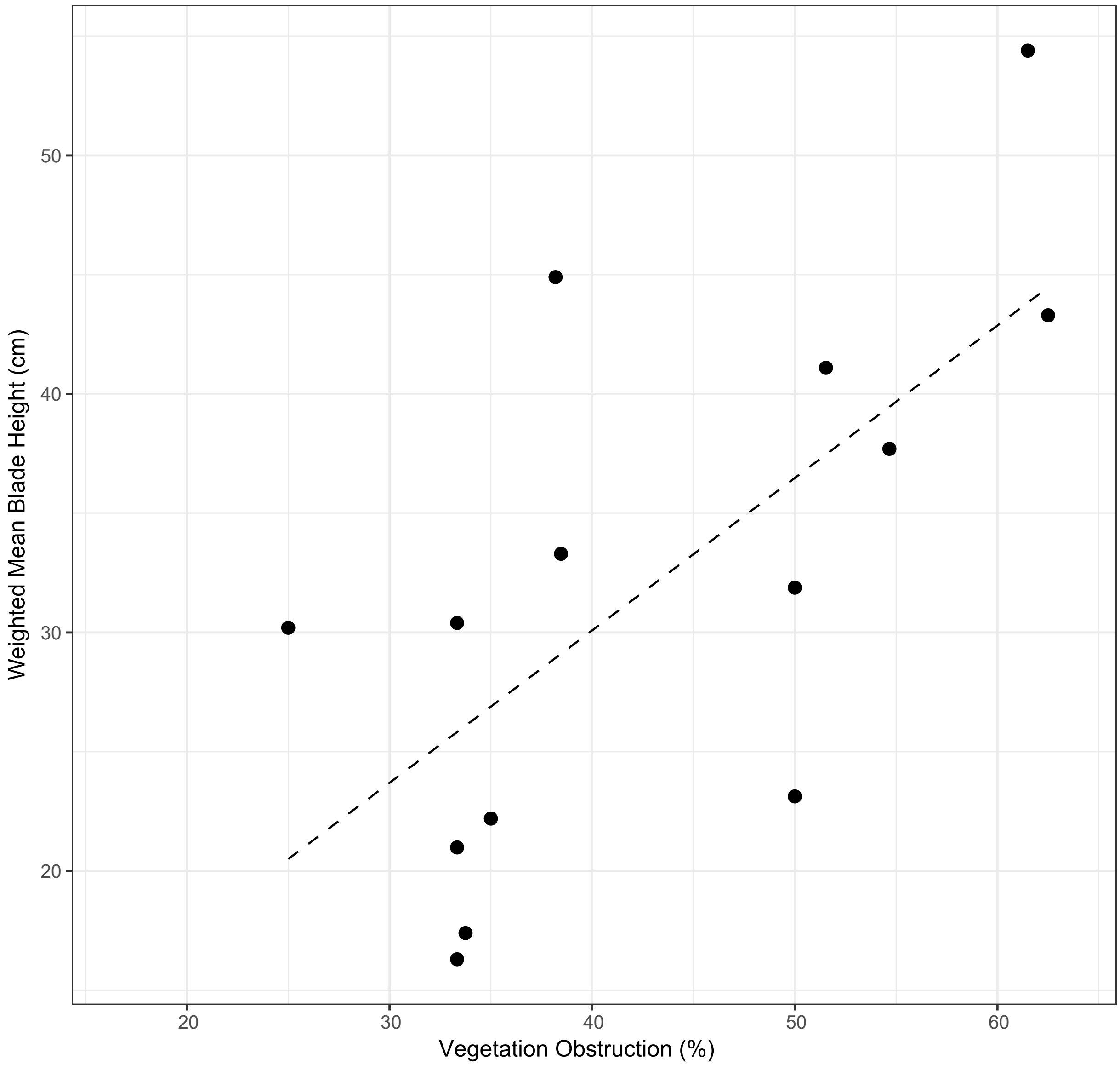


Figure 9. Correlation of the RAM metric Vegetation Obstruction to the SSIM weighted mean blade height (R=0.67; p=0.0091; R^2=0.45).

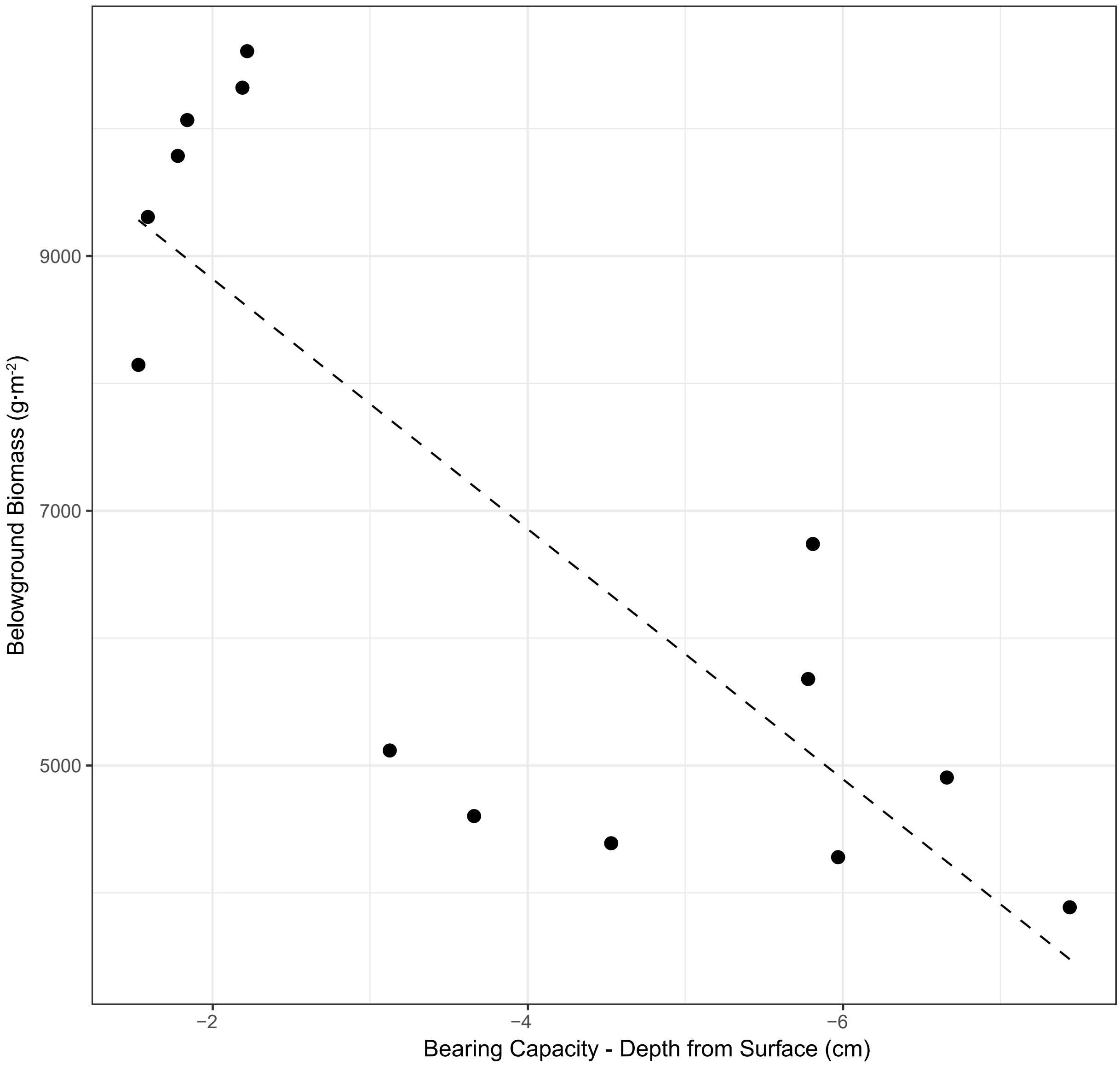


Figure 10. Correlation of the RAM metric bearing capacity to the SSIM below ground biomass (R=0.80; p=0.00057; R^2=0.64).

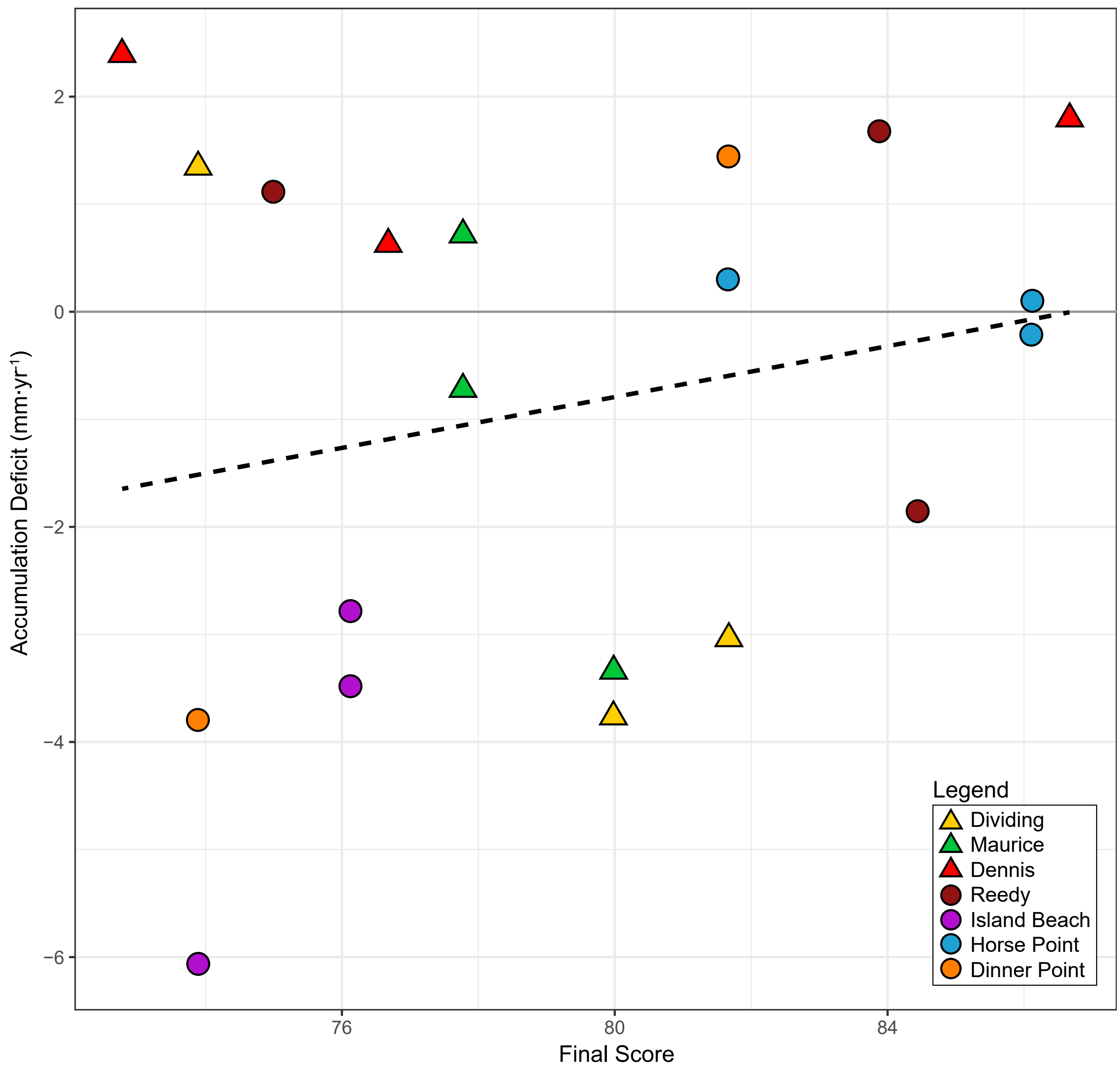


Figure 11. Correlation of RAM Final Scores for condition and accumulation deficits relative to sea level rise, as derived from the elevation change SSIM metric (R=0.22; p=0.348; R^2=0.049).

Conclusion

In this study, we assessed the condition of seven long-term monitoring locations using rapid assessment methods to quantify associations between methodologies and begin discerning how condition may affect function. We sought to 1) understand the condition of SET-MHs relative to watersheds, 2) test correlations between long-term and rapid field methods, and 3) determine whether condition metrics provided insight into sea level rise vulnerability. In summary, we found that SET-MHs in the Delaware Bay were similar in condition compared to watershed scores, but SET-MHs in Barnegat Bay were of better condition than most assessment locations throughout the Bay. Correlation tests also suggested that rapid vegetation methods and Habitat scores may reasonably capture intensive biomass methods. Since vegetation growth is ecologically dependent on inundation, we also found strong correlations with vegetation metrics and Hydrology scores. Such strong correlations may have future utility for mapping. For instance, bearing capacity measurements may help managers infer potentials for belowground carbon storage. Other metrics, however, did not correlate as well (~63% of correlation tests were weak with R values <0.3). Lastly, we found that rapid condition assessments do not associate well with long-term elevation trends derived from SET-MHs and likely are not a good indicator of sea level rise vulnerability.

Reference standards, or metric values that reflect wetlands with minimally impacted functionality and condition, are important for prioritizing, designing, and measuring the success of restoration projects. Reference standards for elevation change, for instance, would help practitioners determine what values trigger immediate action to prevent losses with regard to rising sea levels. By determining the condition of SET-MH sites relative to watershed-wide condition assessments, we found that our Barnegat Bay long-term studies had a slight bias toward sites of better condition (i.e. 50% of SET-MH sites had high Final scores, but only 20% of all assessed sites were of minimally stressed condition). This suggests that the data derived from these sites likely represent good conditions and better functioning than what is average for Barnegat Bay. Therefore, those data may be adequate reference standards for the Barnegat Bay. Conversely, in the Delaware Bay, SET-MH sites were more reflective of average conditions (i.e. 78% of SET-MH sites had moderate Final scores, but more than 49% of all assessed sites were of minimally stressed condition). Thus, data from those SET-MHs should likely not be reference standards exactly, but instead serve as a condition baseline to help guide what minimum reference standard values could be.

Low incidence (less than 25%) of correlation among SSIM and RAM metrics likely reflects the motivation that lead to the development of either rapid or intensive methods. Rapid vegetation methods and intensive biomass methods correlated well, but it is important to note that rapid attribute scores and intensive methods simply seek to derive information at different temporal scales, and most importantly, at different data resolutions. Both methodologies represent efficient and useful ways to obtain two separate, specific research goals (i.e. RAM summarizes condition versus SSIM determines sea level rise vulnerability), but each goal requires different levels of precision, and so, metrics simply do not always serve both purposes. The strength of RAM is that the protocols elucidate general patterns in landscape stressors, covering broad geographical areas, but they lack precision and temporal resolution. Strengths of SSIM protocols are data precision and temporal resolution, but their major weakness is site-specificity. Therefore, the lack of strong correlations do not discount either program and instead underscores the need for both. It may be useful to develop an additional program that covers disparities of RAM and SSIM, such as a program that rapidly collects precise information about sea level rise vulnerability across broader geographical scales (e.g. Cole Erkberg 2017).

References

Arkema, Katie K., Greg Guannel, Gregory Verutes, Spencer a. Wood, Anne Guerry, Mary Ruckelshaus, Peter Kareiva, Martin Lacayo, and Jessica M. Silver. 2013. Coastal habitats shield people and property from sea-level rise and storms. Nature Climate Change 3: 913–918. doi:10.1038/nclimate1944.

Cole Ekberg, Marci L., Kenneth B. Raposa, Wenley S. Ferguson, Kevin Ruddock, and Elizabeth Burke Watson. 2017. Development and Application of a Method to Identify Salt Marsh Vulnerability to Sea Level Rise. Estuaries and Coasts 40. Estuaries and Coasts: 694–710. doi:10.1007/s12237-017-0219-0.

Ferrigno, F., Widjeskog, L. and Toth, S. 1973. Pittman-Robertson Report Proj. W-53-R-1,Job I-G. In Marsh Destruction, Trenton, NJ: New Jersey Department of Environmental Protection.

Kirwan, M.L., Murray, A.B., Donnelly, J.P., and Corbett, D.R., 2011, Rapid wetland expansion during European settlement and its implication for marsh survival under modern sediment delivery rates: Geology, v. 39, p. 507–510, doi:10.1130/G31789.1.

Mudd, S. M. 2011. The life and death of salt marshes in response to anthropogenic disturbance of sediment supply. Geological Society of America 39: 511–512. doi:10.1130/focus052011.1.

Murray, A. B., M. A F Knaapen, M. Tal, and Matthew L. Kirwan. 2008. Biomorphodynamics: Physical-biological feedbacks that shape landscapes. Water Resources Research 44: 1–18. doi:10.1029/2007WR006410.

Narayan, Siddharth, Michael W. Beck, Paul Wilson, Christopher J. Thomas, Alexandra Guerrero, Christine C. Shepard, Borja G. Reguero, Guillermo Franco, Jane Carter Ingram, and Dania Trespalacios. 2017. The Value of Coastal Wetlands for Flood Damage Reduction in the Northeastern USA. Scientific Reports 7. Springer US: 1–12. doi:10.1038/s41598-017-09269-z.

Smith, Joseph A M, S. F. Hafner, and Larry J Niles. 2017. The Impact of Past Management Practices on Tidal Marsh Resilience to Sea Level Rise in the Delaware Estuary. Ocean & Coastal Management 149: 33–41.

Sutton-Grier, Ariana E., Kateryna Wowk, and Holly Bamford. 2015. Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. Environmental Science and Policy 51. Elsevier Ltd: 137–148. doi:10.1016/j.envsci.2015.04.006.