Correlating Elevation to Vegetation Communities and Investigating Operator Error of an Electronic Level and RTK-GPS in a Tidal Freshwater Marsh

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Introduction

There are a number of factors that may control the development of wetland plant communities along the intertidal gradient. The distribution of plant species can depend on salinity, soil, surface level changes, precipitation, and temperature (Adams 1963). Plant communities may also be limited in spatial ranges according to stress factors or the relative availability of nutrients. For example, competition among other plant species could be a limiting factor. A certain species may be able to grow across a large range, but if it is not a competitive species, it could be limited to a smaller area in the marsh because other more competitive species dominate the other areas of the marsh. Another limiting stress factor could be the flooding of the marsh due to the daily tides as well as episodic wind and/or flooding events. If some species are better able to withstand periodic flooding, they may be present in the low marsh, but species that are less able to handle flooding, or can only handle episodic flooding, may be more prevalent at higher elevations.

The relationship of species and elevations is also beneficial for the successful implantation of the restoration of species. The successful restorations of other marshes have used elevation as the primary factor in determining where to plant colonies of vegetation (Crooks et al. 2002). Elevation distributions illustrate where the majority of plant individuals are growing within the marsh. This data can be used to restore plant species to those areas where they grow most successfully.

Tidal wetlands continue to be threatened by sea level rise in all parts of the world. The survival of these wetlands is determined by the ability of the surface elevation of the wetland to move faster than the oceans are rising. Sea level rise alone is estimated to cause the loss of up to twenty percent of global wetlands by 2080 (Webb et al. 2013). The impacts of wetland loss include a release of carbon into the atmosphere, the loss of biodiversity and habitat, and increased vulnerability to storms. Information for the changing elevation of wetlands across the world needs to be monitored to assess the vulnerability of these crucial environments. A coordinated effort to monitor the elevation rise of wetlands will help determine the most threatened areas of wetlands and a proper response can be made to address the situation.

Substantial changes in the elevations of plant communities have been recorded in correlation to areas of sea level rise (Warren and Niering 1993). As the rate of sedimentation increases, vegetation zonation naturally shifts to increase in elevation (Olff et al. 1997). Monitoring the changes in vegetation elevation is important to better understanding the relationship between vegetation succession and sea level rise and predicting the survivability of wetland ecosystems. In general, the more tolerant a species is to inundation, the more likely the species will be able to grow and survive as sea levels rise.

This research will provide an insight of the vulnerability of Jug Bay and surrounding tidal marsh species to the threats of sea level rise. If species primarily grow only in elevations that do not experience much flooding, only episodic flooding, they may have less of a tolerance to flooding. Changing sea levels may be very harmful to the survival of those species. However, species that are used to growing in flooded environments, such as on the low marsh, will most likely be better able to adjust to changing sea levels because they have a tolerance to flooding.

The secondary aim of this project is continuing a study by the National Oceanic and Atmospheric Administration (NOAA) to determine the impacts of the observer on surface elevation measurements using a digital barcode level or Real-Time Kinematic GPS on a marsh surface. The goal is to ensure that no errors are being introduced into our results that could invalidate the results of our study.

NOAA has successfully created a model to diminish tropospheric errors when taking elevation measurements (Ahn et al. 2006). However, little research has been done on the effects of the observer taking surface elevation measurements in a marsh environment. The primary question we are trying to resolve is whether there is a significant effect of the observer on the elevation measurements when the observer is stepping on the marsh he/she is attempting to measure. If there is a significant effect, is it consistent, and can a correction factor be applied? This is an important question because not only does this validate the results of this study, but also many researchers are currently attempting to evaluate and monitor wetland elevations and change. If the weight of the observer has a significant impact on the elevation measurements taken, then any measurements collected will have a bias introduced in their data. That bias will skew their results and may give those researchers different conclusions in their studies. This project is significant for addressing those concerns and ensuring the legitimacy of elevation measurements in marsh environments.

Study Site

This study was conducted on the Jug Bay tidal freshwater marsh, located along the upper portion of the Patuxent River, Maryland, a tributary of the Chesapeake Bay.

Tidal freshwater marshes are diverse ecosystems that combine the characteristics of freshwater and saltwater marshes. The marsh is divided into a low marsh, the lowest level of the marsh, and the mid-high marsh. The low marsh is often dominated by *Nuphar advena* (spatterdock), *Zizania aquatic* (wild rice), *Pontederia cordata* (pickerelweed), *Peltandra virginica* (arrow arum), and *Sagittaria latifolia* (broadleaf arrowhead).

The mid-high marsh region is dominated by a larger number of species including *Typha spp.* (cattail), *Impatiens capensis* (jewelweed), *Acorus americanus* (sweetflag), *Carex spp* (sedge), *Sparganium eurycarpum* (giant burreed), *Leersia oryzoides* (rice cutgrass), *Persicaria arifolia* (tearthumb), *Hibiscus moscheutos* (mallow), *Pilea pumita* (clearweed), *Amaranthus cannabinus* (water hemp), *Murdannia keisak* (dayflower), *Symphyotrichum puniceum* (purplestem aster), *Veronia noveboracensis* (New York ironweed), and *Bidens leavis* (bur marigold).

The tidal datums were calculated by NOAA COOPS in Edge Harbour as the closest NOAA tide station to Jug Bay Wetlands Sanctuary. These datums were assumed to be fairly accurate estimations of the water levels at Jug Bay. The Mean High Water was 0.162 meters above sea level. The Mean Sea Water was -0.081 meters. The Low Mean Water was -0.328 meters.

Methodology

All measurements for this study were collected from three main areas within the Jug Bay Wetlands complex: Mataponi Creek, Railroad Bed, and Western Branch (Figure 1). The data was collected along existing transects that had catwalks extending from the water's edge towards the marsh.

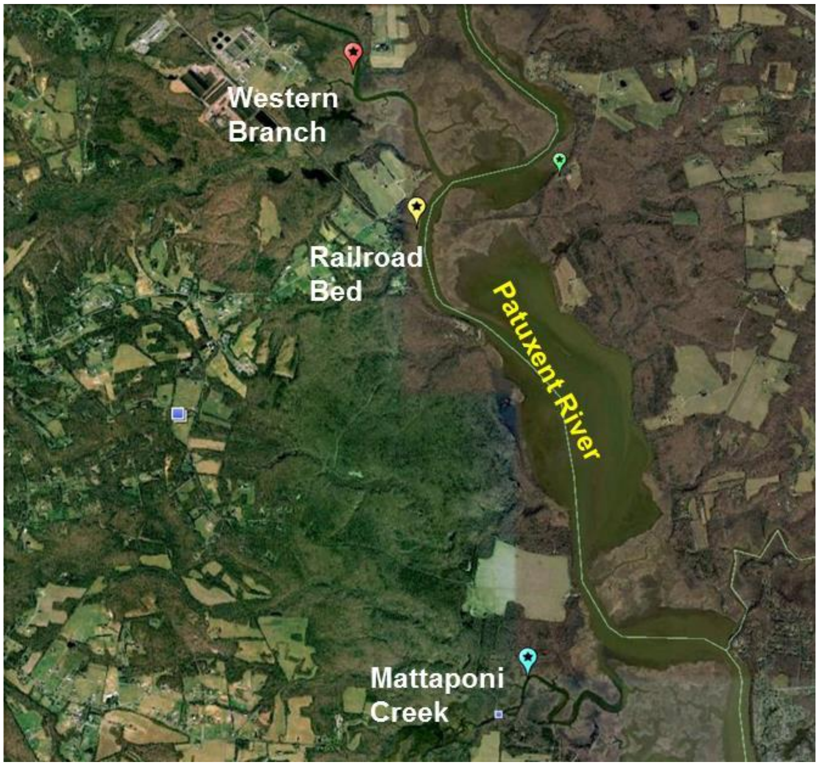

Figure 1. Map showing main study areas within the Jug Bay wetlands complex.

Linking Elevation to Marsh Vegetation Zonation

Elevation measurements for a specific marsh species or community of species were collected using a Leica Geosystems Sprinter 250M digital barcode level. The Sprinter was used to measure the height difference of the wetland soil surface from a local Surface Elevation Table (SET) having a known elevation. A backsight was taken to the level rod on top of the SET mark and then multiple foresights were taken to the level rod placed at each of the identified plant community locations. If two or more plant species were present at the same point, all of the species were recorded for that measurement. The accuracy of the instrument was checked about every 20 measurements by making a reading back to the reference SET. This process was repeated multiple times as needed to cover the extent of the marsh.

The following procedures were followed when measuring elevation for different species communities or association of species:

1. Homogeneous patches: Approximately 20 measurements were taken randomly within the patch. A homogeneous patch was defined as an area of at least 1 m^2 colonized by a single species.
2. Mixed species areas: Elevation measurements were taken on the right, center, and left of transects drawn parallel to the marsh catwalk. All species growing around a specific location were recorded and considered to have the same elevation.
3. Distinct division lines between two species: In some areas, there was a clear division line between two species, particularly in the low marsh zone. Distinct division lines were measured between *Typha spp.* (cattail) and *Nuphar advena* (spatterdock), between *Typha spp.* And *Zizania aquatica* (wild rice), and between *Nuphar advena* and *Zizania aquatica.* Elevation measurements were taken right at the division line to see if the change from one species to another could be linked to a “significant” elevation change.
4. Species with restricted distribution: These were defined as species growing in a limited/small area within the marsh; they were targeted to characterize their elevation requirements. Species with restricted distribution measured in this study included *Bolboschoenus fluviatilis* (River bulrush), *Carex crinita* (Sedge), *Hibiscus moscheutos* (Marsh mallow), *Symphyotrichum puniceum* (Aster), *Schoenoplectus tabernaemontani* (Great bulrush), *Schoenoplectus pungens* (Common Three-Square), *Spartina cynosuroides* (Cordgrass), and *Onoclea sensibilis* (Sensitive fern).

Data Analysis:

The following procedures were used to analyze the data:

1. T-tests: A two-sample t-test with 90% confidence was used to analyze each of the elevation main species against each other. This was conducted to find if the main species grew in the same areas or if they each had separate niches to fulfill.
2. Descriptive Statistics: Excel was used to find the average elevations, minimum elevations, maximum elevations, ranges of elevation, and standard deviations of elevation.

Investigating User Error

The Leica Geosystems Sprinter 250M digital barcode level was used to investigate the operator error while surveying the marsh surface. The process was repeated using a Trimble R8 GNSS Real-Time Kinematic Global Positioning System (RTK-GPS) package (rover and base). Measurements were taken in both the high marsh (more vegetation and firmer soil) and the low marsh (softer sediments).

Measurements were taken along boardwalks constructed in the marsh. In the first method (leveling only), 25 measurements were first taken from the boardwalk, reaching over the marsh and placing the level rod on the marsh surface. Then, when the user was standing in the marsh, the 25 measurements were repeated.

The second method (leveling and RTK-GPS) was to take two measurements, one on each side of the boardwalk while standing on the boardwalk. Subsequently, the observer would step onto the marsh surface and stood about 0.75 - 1.0 meter from the location of measurement and each measurement was repeated. Then, the observer would get back on the boardwalk and move down to the next set of measurements.

Measurements from the marsh surface were always taken second (after the initial measurement from the boardwalk) to avoid any prolonged influence from having altered the sediment surface due to the weight of the observer. The effect of the observer could be confounded with a "sequence" effect because the first measurement could have depressed the marsh surface, so the surface may be lowered before the observer even stepped onto the marsh. To test for this, a separate set of measurements were taken twice, in succession, from standing on the boardwalk in one location. After the rod/rover pole was placed in the marsh and the elevation was recorded, the observer would lift up the rod/rover pole, wait a few seconds, and place the rod back in the marsh at the same location.

The repeatability error was also estimated by taking measurements on top of bolts embedded within the boardwalk. In a similar manner, the rod/rover pole was placed on the bolt and the elevation was recorded. The rod/rover pole was picked up and placed back on the same bolt. These measurements were to show the variability of the instrument itself. The observer was careful not to stand on any planks of wood directly touching the bolt. The bolts were firmly anchored and assumed to have constant elevation for the duration of the paired observations, so any variability between the two measurements could not be attributed to user error, but of the instrument's error itself.

The differences between the measurements taken from the boardwalk and those taken from the marsh represent three sources of error: 1) the error induced by the observer standing on the marsh; 2) any bias due to the sequence of measurements; 3) any systematic drift in the measurements themselves. For all pairs of measurements taken in this part of the study, paired T-tests were conducted and evaluated at the 95% confidence level (5% Type I error). Since all three components of the total error were evaluated, the effect of the observer, level rod, and RTK rover by itself was estimated by substitution.

Results

Linking Elevation to Marsh Vegetation Zonation

Close to 900 elevation measurements were taken characterizing a total of 24 marsh plant species shown in Table 1.

Table 1. Summary of all species measured with information (if known) about their tolerance to flooding.

Scientific Name	Common Name	Species Code	Tolerance to Flooding
Bidens Laevis	Bur marigold	BILA	Flooding reduced germination rate[7]
Bolboschoenus fluviatilis	River bulrush	BOFL	Reduced abundance in flooded environments[8]
Carex crinita	Sedge	CACR	Flooding reduced growth rate[9]
Eleocharis	Sedge	EL	Reduced abundance with 10 cm flooding[10]
Galium	Bedstraw	GA	
Hibiscus moscheutos	Marsh mallow	HIMO	Reduced abundance in flooded environments[11]
Impatiens capensis	Jewelweed	IMCA	Flooding reduced germination rate[12]
Leersia oryzoides	Rice cutgrass	LEOR	Flooding reduced germination rate[10]
Murdannia keisak	Dayflower	MUKE	
Nuphar advena	Spatterdock	NUAD	Not affected by flooding[13]
Onoclea sensibilis	Sensitive fern	ONSE	
Peltandra virginica	Arrow arum	PEVI	Not affected by 10 cm flooding[10]
Persicaria arifolia	Tearthumb	PEAR	
Persicaria hydropiper	Tearthumb	PEHY	
Pilea pumila	Clearweed	PIPU	Reduced abundance with 10 cm flooding[10]
Pontederia cordata	Pickerelweed	POCO	Flood tolerant
Sagittaria latifolia	Broadleaf arrowhead	SALA	
Schoenoplectus pungens	Common Three-Square	SCPU	
Schoenoplectus tabernaemontani	Great bulrush	SCTA	
Sparganium eurycarpum	Giant burweed	SPEU	
Spartina Cynosuroides	Cordgrass	SPCY	
Symphyotrichum puniceum	Purplestem aster	SYPU	

Scientific Name	Common Name	Species Code	Tolerance to Flooding
Typha spp.	Cattail	TY	Not affected by periodic flooding[14]
Zizania aquatica	Wild rice	ZIAQ	Reduced plant size and reproductive production with 30-40 cm flooding[15]

T-tests were run to see if any of the plant species had closely related distributions. Out of the eleven main communities, the only pairings where the two population means were equal for 90% confidence were *Impatiens capensis* and *Hibiscus moscheutos*, *Impatiens capensis* and *Sparganium eurycarpum*, and *Peltandra virginica* and *Persicaria arifolia*. Only these three pairings have equal means, so they will grow in the same areas as each other. All other species grow in separate elevation spans (although they may overlap). This indicates that except the three mentioned pairings above, all other species have distinct niches that they fulfill.

Table 2 provides the descriptive statistics of eleven of the most dominant plant communities measured during this study. Out of all of the species, the largest range in elevation was less than .8 meters. Of the eleven most prominent plant communities, all three of the low marsh species, *Nuphar advena* (0.775 m), *Zizania aquatica* (0.516 m), and *Pontederia cordata* (0.772 m) had elevation ranges over 0.4 m. *Typha spp.* (0.423 m), *Peltandra virginica* (0.567m), and *Persicaria arifolia* (0.436 m) also had elevation ranges above 0.4 m. The species with elevation ranges under 0.4 m were *Hibiscus moscheutos, Symphyotrichum puniceum, Impatiens capensis, Sparganium eurycarpum,* and *Sagittaria latifolia.*

Table 2. Summary of elevation data for eleven of the most dominant species measured during this study.

Species	Number of Observations	Average Elevation (m)	Minimum Elevation (m)	Maximum Elevation (m)	Range (m)	Standard Deviation
Pontederia cordata	78	-0.037	-0.424	0.348	0.772	0.245
Nuphar advena	332	0.140	-0.336	0.440	0.775	0.180
Mean Low Water			**-0.328**			
Zizania aquatica	153	0.121	-0.212	0.305	0.516	0.121
Mean Sea Water			**-0.081**			
Peltrandra virginica	429	0.313	0.002	0.569	0.567	0.117
Persicaria arifolia	87	0.348	0.087	0.523	0.436	0.063
Typha	155	0.297	0.089	0.512	0.423	0.102
Sparganium eurycarpum	125	0.417	0.145	0.518	0.373	0.082
Mean High Water			**0.162**			
Impatiens capensis	210	0.409	0.181	0.546	0.365	0.069
Hibiscus moscheutos	73	0.394	0.201	0.546	0.346	0.094
Sagittaria latifolia	74	0.440	0.278	0.523	0.245	0.048
Symphyotrichum puniceum	45	0.454	0.364	0.516	0.152	0.035

From Figure 2, we can see that a majority of the plants surveyed had their minimum elevations above the Mean High Water level indicating that those plants are not as tolerant to flooding as the species located in lower elevations. Those species include *Bolboschoenus fluviatilis, Carex crinita, Eleocharis, Galium, Hibiscus moscheutos, Impatiens capensis, Leersia oryzoides, Onoclea sensibilis, Pilea pumita, Sagittaria latifolia, Schoenoplectus pungens, Schoenoplectus tabernaemontani, Spartania Cynosuroides,* and *Symphyotrichum puniceum.* All of the vegetation had their maximum elevations above the Mean High Water level, so all of the species are capable of growing in a less-flooded environment. A few plant species had minimums between the Mean Sea Level mark and the High Sea Level mark. This indicates that those species can tolerate some flooding, but in general are above the water level. Those species include *Murdannia keisak, Persicaria arifolia, Persicaria hydropiper, Peltandra virginica,* and *Typha spp.* Two species had minimum elevations below the Mean Sea Level, but above the Mean Low Water. This indicates that those species are very tolerant to flooding and can typically spend significant time under water (although the average individual does not). Those species include *Bidens laevis* and *Zizania aquatica.* Two species had minimum elevation values below the Mean Low Water level. This indicates that those species are highly tolerant to flooding. Those species are *Nuphar advena* and *Pontederia cordata.*

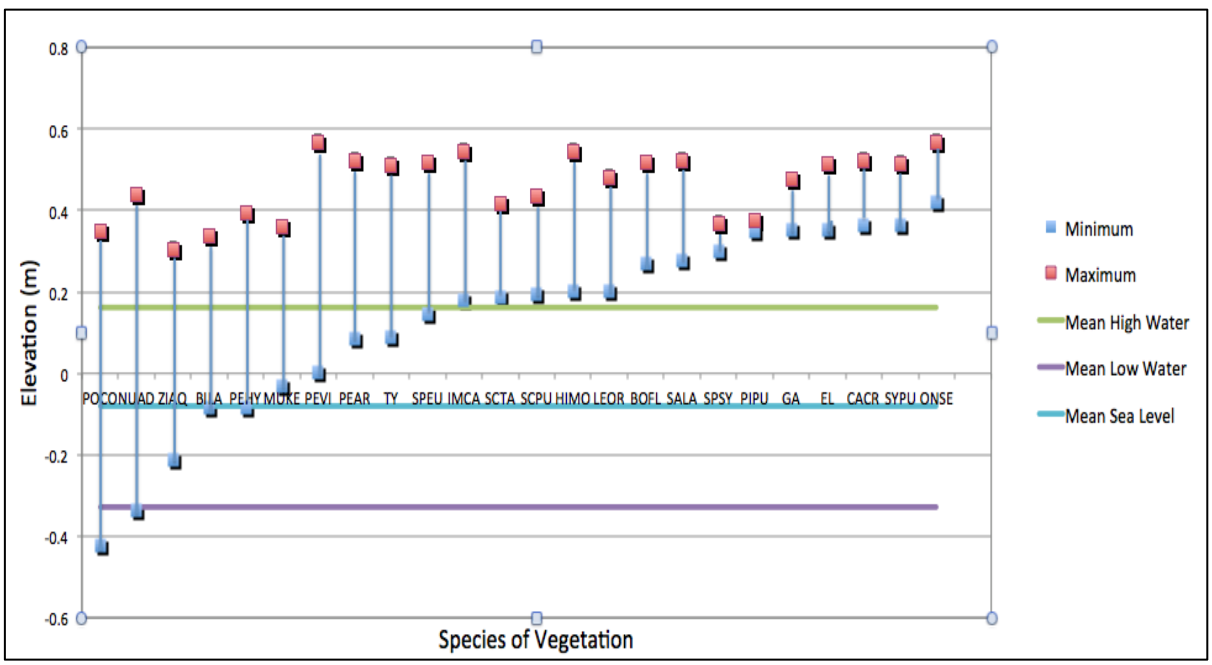

Figure 2. Elevation ranges for all twenty-four species measured during this study. Tidal datums: mean low water (MLW), mean sea level (MSL), and mean high water (MHW) were added as reference points.

The frequency distributions of the same eleven plant communities separated by low and mid-high marsh are shown in Figure 3 below. They are separated by low marsh species and high marsh species to show how the individual species distributions compare to each other.

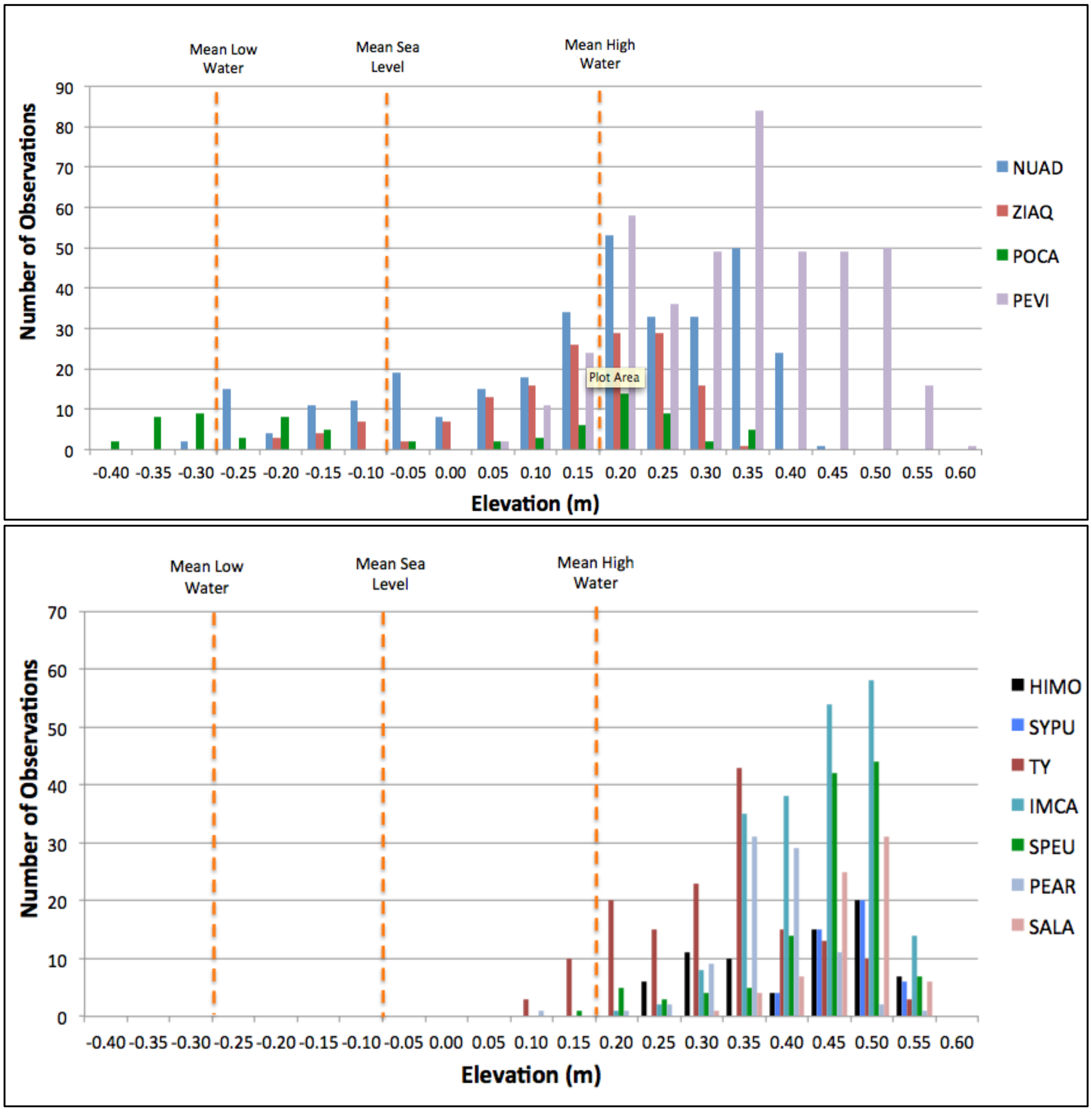

Figure 3: Frequency distributions of elevation data for the species located in the low marsh species: *Nuphar advena* (NUAD), *Zizania aquatica* (ZIAQ), and *Pontederia cordata* (POCO), and *Peltandra virginica* (PEVI) and the high marsh species: *Hibiscus moscheutos* (HIMO), *Symphyotrichum puniceum* (SYPU), *Typha spp.* (TY), *Impatiens capensis* (IMCA), *Sparganium eurycarpum* (SPEU), *Persecaria arifolia* (PEAR), and *Sagitarria latifolia* (SALA).

Investigating User Error

When using the Leica Sprinter level, there was not a significant difference using 95% confidence between the measurements taken on and off the boardwalk for either the high marsh (Mean difference = 0.003024, t-statistic = 2.855388) or low marsh (Mean difference = 0.001359, t-statistic = 1.491545) for all surface elevation measurements.

Similarly, when the RTK-GPS equipment was used, the methodology of taking two measurements on the boardwalk and two measurements off of the boardwalk, there was no significant difference between the two measurements for the high marsh (Mean difference = -0.00135, t-statistic = 0.852083) and the low marsh (Mean difference = 0.000133, t-stastic = 0.100039).

For repeated measurements using the digital barcode level on the marsh surface, there was no significant difference between surface elevation measurements (Mean difference = -0.00187, t-statistic = 3.972352). For the repeated measurements using the digital barcode level on the bolts on the boardwalk, there was no significant difference between surface elevation measurements (Mean difference = 0.0002, t-statistic = 0.13135).

For the repeated measurements taken using the RTK-GPS on the marsh surface, there was no significant difference between the surface elevation measurements (Mean difference = -0.66667, t-statistic = 0.804207). For the repeated measurements taken on the bolts on the boardwalk, there was no significant difference (Mean difference = .1, t-statistic = 0.13043).

Table 3. Summary of the t-tests performed on all of the elevation measurements taken in the second phase of the project.

Instrument	Method	Mean Difference (m)	T-statistic	Significant Difference
Leica Sprinter	On/Off Boardwalk- High Marsh	0.0030	2.8554	no
Leica Sprinter	On/Off Boardwalk- Low Marsh	0.0014	1.2915	no
Leica Sprinter	Repeated Measurements- Marsh Surface	-0.0019	3.9723	no
Leica Sprinter	Repeated Measurements- Bolts	0.0002	0.1314	no
RTK-GPS	On/Off	-0.0014	0.8521	no

Instrument	Method	Mean Difference (m)	T-statistic	Significant Difference
	Boardwalk- High Marsh			
RTK-GPS	On/Off Boardwalk- Low Marsh	0.0001	0.1000	no
RTK-GPS	Repeated Measurements- Marsh Surface	-0.6667	0.8042	no
RTK-GPS	Repeated Measurements- Bolts	0.1000	0.1304	no

Discussion

Linking Elevation to Marsh Vegetation Zonation

The elevation distributions of marsh species collected are valuable information for future studies and projects. It also serves as an indicator on the future of these marsh species in an ever-changing environment.

The elevation distributions that we collected serve as important resources for restoration projects. Most projects require an elevation profile before starting and that is essentially what we have collected. The elevations where the majority of individuals of a species grow would be the best places to implement restoration projects because that is where the species will most likely be able to grow and spread.

As sea level rise becomes more of a threat, studies have been done to examine the potential effects on tidal freshwater marshes. The plant species located in the lower marsh, such as *Pontederia cordata*, *Nuphar advena*, and *Zizania aquatica*, generally have large elevation ranges and can grow in more flooded areas of the low marsh as well as the less-flooded mid-high marsh. These species are very tolerant to flooding because in the low marsh, they experience frequent inundation. When sea levels rise, these low marsh species will most likely be able to survive because they already have communities growing on higher elevations, but also, as a species, are tolerant to flooding. However, high marsh species, such as *Hibiscus moscheutos*, *Symphyotrichum puniceum*, *Impatiens capensis*, *Sparganium eurycarpum*, and *Sagittaria latifolia*, that are not very tolerant to flooding and are limited to a small elevation range may experience difficulties in a changing environment. If those elevations become not available or increased flooding occurs in those elevations, these species may not survive.

Investigating User Error

Since there was no significant difference between either the low marsh or high marsh for measurements taken on and off the boardwalk in an alternating fashion, stepping on the marsh most likely does not effect the measurements taken by either the electronic level or the Real-Time Kinematic GPS. This is important because many researchers make use of this equipment to do studies on elevations and zonation of plant species and shorelines. These researchers often work in environments that do not have boardwalks, where they have to physically step on the marsh. Those steps will not affect their measurements and, thus, will not introduce a bias into their results.

However, there was a significant difference for the methodology of taking 25 measurements on the boardwalk and then going back and taking the 25 measurements off of the boardwalk. This is most likely a result of user error in the placement of the rod. Flags were used to mark the locations of the spots of measurement. After taking 25 measurements, the user most likely doe not remember where exactly the rod was placed previously, introducing an error when placing the rod again. Therefore, although we did not find an error of the user for stepping on the marsh, the user needs to be careful about where exactly the rod is being placed.

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