Title
Make Wetlands Great Again: Reviewing Salt Marsh Vegetation Restoration in the Tijuana River National Estuarine Research Reserve

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Make Wetlands Great Again

Reviewing salt marsh vegetation restoration in the Tijuana River National Estuarine Research Reserve

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The Tijuana River National Estuarine Research Reserve (TRNERR) is in the planning process of Phase II of its Tijuana Estuary Tidal Restoration Program, which incorporates adaptive management strategies. As a result of the first phase, vegetation monitoring sites were set up throughout the salt marshes at the TRNERR for long-term data collection. This paper is an initial exploratory look into the data collected so far at both the vegetation community and individual species level. The elevation distribution of selected species were calculated in order to inform their inclusion in future restoration efforts. Furthermore, indicator species were chosen to monitor into the future to track shifts in marsh distribution due to sea level rise.

Figure 1. The Tijuana River watershed (in green) and TRNERR boundaries (in red).

I. INTRODUCTION

Tijuana River National Estuarine Research Reserve Description

Located in San Diego County, CA just above the U.S.-Mexico border, the Tijuana River National Estuarine Research Reserve (TRNERR) is the largest remaining intact salt marsh ecosystem in southern California (Figure 1). Although the estuary lies within the United States, nearly three-quarters of the Tijuana River watershed is in Mexico (Zedler and Nordby 1986). The watershed has been heavily impacted by human activities; raw sewage and sediment inputs occur from the city of Tijuana, Mexico and both the U.S. and Mexico contribute urban and agricultural runoff to the estuary (Zedler and West 2008). Since the 1800s, it's estimated that 60-80% of wetland habitats and tidal prism (i.e. the volume of water that flows in and out of an estuary between tides) have been lost (TETRP 2008).

Characterized by a Mediterranean-type climate, the TRNERR experiences cool, wet winters and warm, dry summers with an average annual rainfall of 25 cm (Uyeda et al. 2013). The rainy season (approximately January-April), results in infrequent, but heavy, stream flows during the winter. Flash floods and sea storms during this period import excessive amounts of sediment that bury salt marsh plants in the estuary (Zedler and West 2008).

The southern arm of the estuary has experienced particularly intense degradation due to its proximity to the city of Tijuana and tributary canyons.

Salt Marsh Zones

Salt marshes, including those found at the TRNERR, are divided into several zones depending upon the elevation, physical conditions and vegetation found there (Zedler and Nordby 1986). Typically, there are three marsh zones: low marsh, mid marsh and high marsh. The lower bounds of each zone is defined by the amount of tidal influence that zone experiences daily, while the upper limits of plant distribution are typically defined by factors such as plant competition and facilitation (Zedler and Cox 1985). The low marsh exists at the lowest elevations of the marsh and experiences the longest periods of tidal inundation. It is dominated by cordgrass (*Spartina spp.)* (Zedler and Cox 1985). The mid marsh sits above the low marsh, experiences less tidal influence, and tends to be dominated by pickleweed (*Salicornia pacifica).* Above the mid marsh, the high marsh experiences the least amount of tidal influence and has the greatest variety of species. Several species may dominate this area, including Parish's glasswort (*Arthrocnemum subterminale*), shore grass (*Distichlis littoralis*) and alkali heath (*Frankenia salina*). The high marsh gradually gives way to the upland transition zone, which contains a mix of marsh and upland plants (Zedler and Nordby 1986).

TRNERR Restoration Efforts

As part of the TRNERR Comprehensive Management Plan, the Tijuana Estuary Tidal Restoration Program (TETRP) was established in 1991 in order to provide the framework to restore the tidal prism and 500 acres of wetlands in the southern portion of the Reserve to as near natural conditions as possible. In 1997, the first project of Phase I was completed with the creation of a 1,200 foot channel connecting the northern side of the Oneonta Slough to the tidal ponds southeast of the visitor center (TRNERR CMP 2010). The second project, completed in 2000, involved the restoration of Model Marsh, a 20-acre salt marsh that was created to serve as an experimental template for future restoration efforts. Model Marsh was designed and implemented in order to look at the influence of tidal creeks on the marsh plain. It was created with six replicate cells, three with tidal creeks and three without tidal creeks. Additional studies on the marsh have looked at planting methodologies and assessed marsh development, which has led to a large body of literature on the site (see Zedler and West 2008; Wallace et al. 2005 for examples).

The strategy has since been adjusted, reducing the total acreage to be restored from 500 acres to approximately 200-250 acres (TRNERR CMP 2010). This is largely due to sedimentation and degradation risks in the southernmost section of the southern arm of the estuary because that area is particularly vulnerable to flood damage (TRNERR CMP 2010). In 2008, a Feasibility and Preliminary Design Study was completed as a continuation of this new restoration objective. Based on the results of the study, seven overarching goals were developed:

1) Increase tidal prism
2) Restore areas of former salt marsh, tidal channel, and mudflat affected by sedimentation to the maximum extent possible
3) Restore barrier beach and dunes
4) Increase habitat for endangered species
5) Increase area of undisturbed transition zone
6) Incorporate a berm to prevent sudden loss of restored habitat from flood events
7) Incorporate research and adaptive management

This plan is part of the larger Recovery Strategy by the Tijuana River Valley Recovery Team, a bi-national collaboration of more than 30 federal, state and local agencies focused on addressing sediment, trash and other environmental issues.

Current Status of TETRP and Research Questions

As the TETRP moves into its second phase, which includes the restoration of 80 acres around Model Marsh, the TRNERR is using adaptive management to incorporate information gathered from the first phase's restoration efforts. A critical part of the adaptive management aspect includes long-term vegetation monitoring of transects set up around various areas of the Reserve. Measuring the plant cover at these transects in the spring and fall of every year provides a database of useful information that can be applied to future restoration projects and can be used to track sea level rise over time.

Furthermore, the 2008 Feasibility and Preliminary Design Study detailed the subtidal and intertidal zones at TRNERR for restoration purposes, including information on native plant installation and slope grading. The feasibility study defined these habitat breaks according to Zedler and Cox (1985) and broke the habitat areas into seven sections: subtidal, frequently flooded mudflat, frequently exposed mudflat, low marsh, mid marsh, high marsh and upland.

This study utilized that vegetation data set in order to characterize the plant communities across the elevation gradient at six different sites on the Reserve and create a baseline for future restoration. Specifically, I wanted to answer the following questions: 1) Can the marshes at the TRNERR be divided into distinct zones by the species found there and are these zones similar across sites? 2) What is the elevation distribution of selected species frequently found within the Reserve? and 3) What species might be good to monitor in order to track changes in marsh distribution due to sea level rise? This evaluation will help to inform future restoration efforts, especially as the sea level begins to rise and marsh distributions change.

II. METHODS

Description of Vegetation Transects

This report utilized an existing vegetation database established in 2012. Six sites within the TRNERR are observed for plant species presence and percent cover in the spring and fall seasons each year (Figure 2). Each site contains one to four transects and each transect contains five to nine 1 m^2 quadrats, marked by two permanent stakes, where the

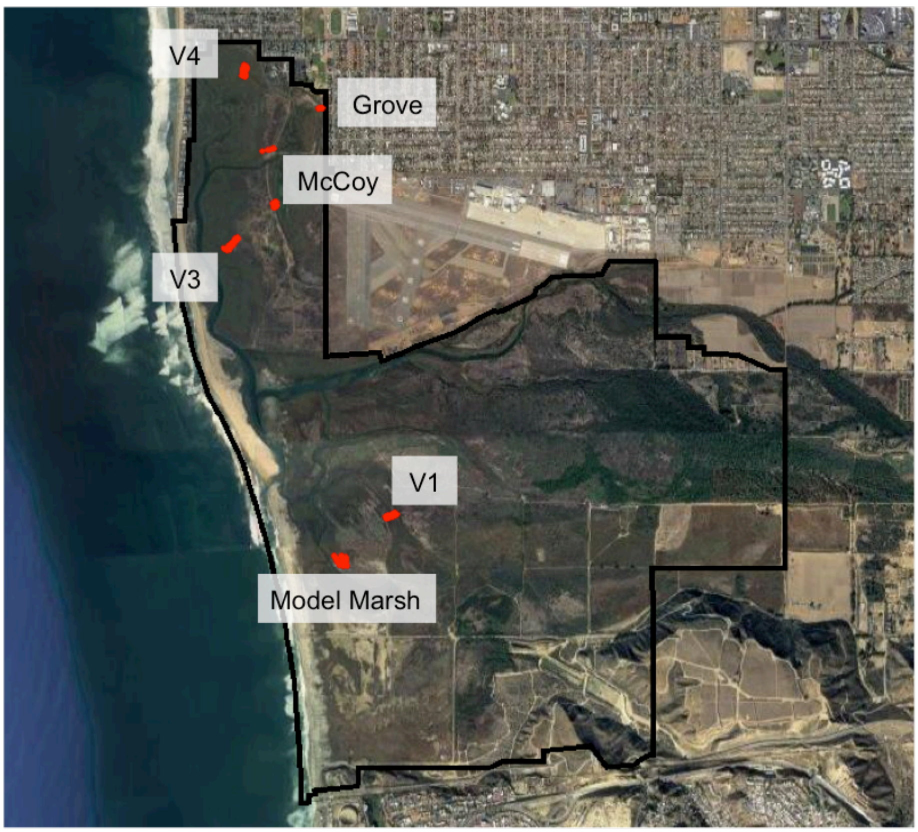

Figure 2. Location of vegetation transects within TRNERR.

vegetation observations are made (Table 1). Transects run perpendicular to the elevation gradient from the low marsh to the upland and vary in length from 20 to 100 m, depending on the steepness of the elevation at that site.

Site	Length (m)	Number of Transects	Number of Quadrats per Transect
Grove	24	1	5
McCoy	20, 20, 21, 74	4	5 to 8
Model Marsh	54, 59, 69	3	7
V1	67, 68, 69	3	9
V3	95, 99, 100	3	8
V4	60. 60.5, 64	3	8

Table 1. Vegetation transect sites broken down by transect length, number of transects per site and number of quadrats per transect.

Vegetation Transect Methodology

At each transect a 1 m^2 PVC square is laid down on the stakes marking each quadrat. The percent cover by plant species is recorded for each quadrat along with bare ground and litter. Due to the three dimensional structure of the plant canopy, the total percent cover for a single quadrat may exceed 100% since multiple plants can occupy the same space at different heights. The species with the maximum canopy height and species with the dominant canopy height are also recorded along with the height measurements for each. Percent cover and other measurements are recorded in the field on data sheets designed for each specific transect. Quadrats that extend into areas with *Spartina foliosa* are not measured in the spring due to nesting of the federally-endangered Ridgway's rail (*Rallus longirostris levipes*).

Vegetation Database and Percent Cover Analysis

Field measurements are transferred from the field sheets to an online Microsoft Excel worksheet, with one individual worksheet serving each survey season (e.g. fall 2012, spring 2014). For this study, the data from the individual worksheets were combined into a single worksheet and reorganized from a crosstab format to a normalized format. The average percent cover figures that were used for the analysis were calculated for each marsh zone by averaging the percent cover of each quadrat within a single transect that fell within the same zone. That number was then averaged across all transects within the site to get a single average per species at each zone across a single site. The new format was analyzed using Tableau, a data analysis and visualization software program, and results were calculated separately for the spring and fall of 2016.

Elevation Database and Analysis

Elevation data for the transects were collected in March 2017 by researchers with the Southwest Wetlands Interpretive Association. Five points were collected at each quadrat, one in each corner of the 1m^2 area and one in the center. Data points were collected in meters in North American Vertical Datum 1988 (NAVD 88) and each point was later assigned to its corresponding quadrat using ArcGIS. The five points in each quadrat were averaged together to determine the average elevation for each quadrat and exported into Microsoft Excel for analysis in Tableau.

Marsh Zones

The delineations for the marsh zones are based on Zedler and Cox (1985) and were chosen because they are the same habitat breaks that will be used in future restoration efforts at the TRNERR. The original research broke the habitat up into seven different zones, however for the purpose of this study only four zones - low marsh, mid marsh, high marsh and upland - were used because they are the only zones in which the vegetation transects lie. The marsh zones were originally calculated in feet in National Geodetic Vertical Datum 1929 (NGVD 29) and were converted to meters in NAVD 88 to match the transect elevation data. This resulted in the following ranges for each marsh zone: low marsh = 1.01 - 1.31 m, mid marsh = 1.31 - 1.77 m, high marsh = 1.77 - 2.11 m and upland = >2.11 m.

Non-Metric Multidimensional Scale Analysis

Non-metric multidimensional scale (MDS) analysis was performed on the vegetation data in order to evaluate the similarity of the marsh zones across sites. Percent cover was calculated for each marsh zone at each site by averaging the percent cover of each quadrat within the same zone in each transect. That number was then averaged across all transects within a site to get a single average per species within each zone at each site. Bare ground and litter were omitted from the analysis and the rest of the species data were reformatted to the correct matrix configuration in Excel and the analysis was conducted through the software Primer 5.

III. RESULTS

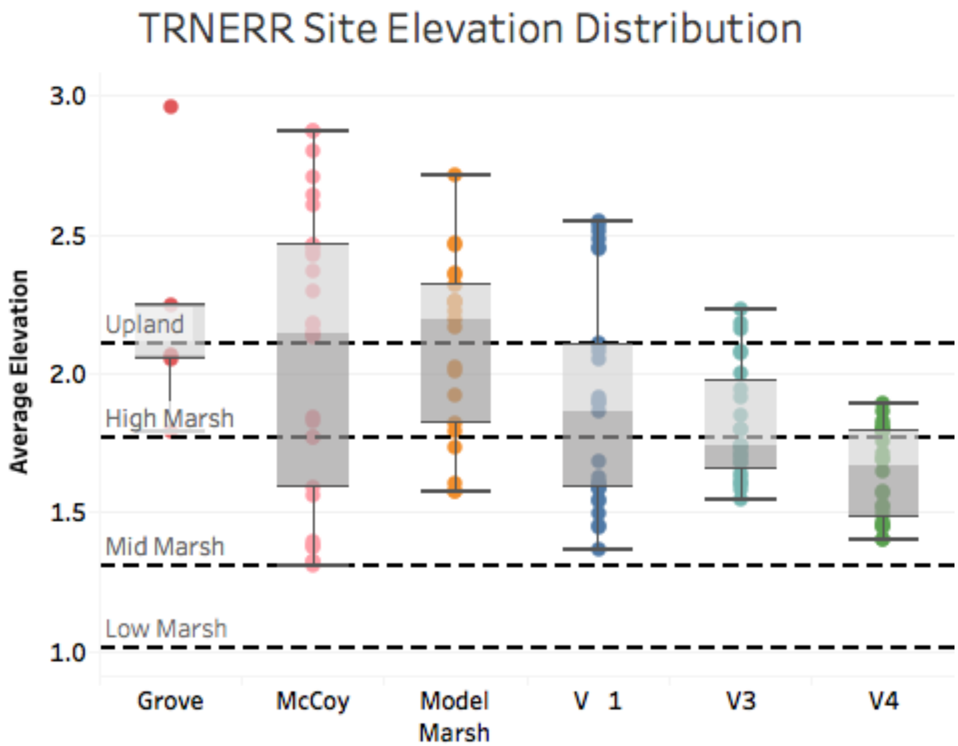

Figure 3. Elevation distribution of vegetation sites at the TRNERR with Zedler and Cox (1985) habitat break lines included for reference. Points have been overlaid with box plots to show the distribution of the data. The box plots can be divided into four sections, the two arms and the two boxes. Each section represents 25% of the data and the line between the two boxes indicates the median.

Transect Elevations

The elevation distribution for each site was calculated and compared to the marsh habitat zones established by Zedler and Cox (1985) (Figure 3). Elevation range varied from site to site, with McCoy exhibiting the greatest range and V4 the smallest. McCoy is also the only site to cross all four marsh zones. The remaining five sites extend from the mid marsh to the upland and do not reach any part of the low marsh. Three sites, V1, V3 and V4, sit with more than 50 percent of their elevation distribution below the upland zone. Furthermore, more than 50 percent of V3 and V4 occupy the mid marsh. The remaining three sites, Grove, McCoy and Model Marsh, have a majority of their elevation distributed in the upland.

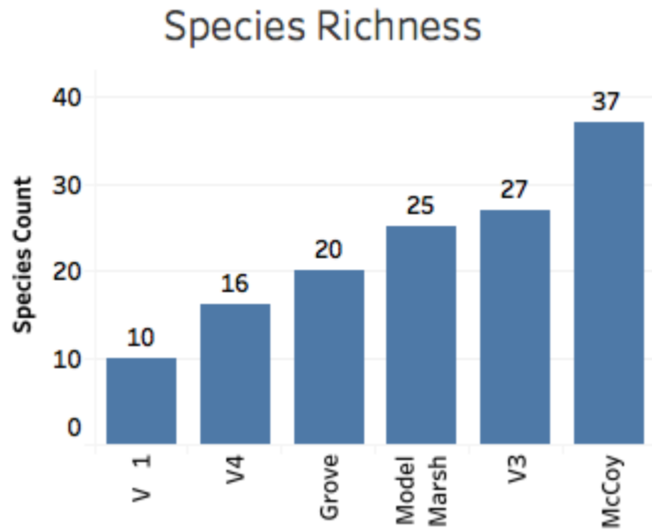

Figure 4. Count of unique species identified at each site.

Vegetation Transects

Since monitoring began in 2012, 49 unique plant species have been identified across all six sites. Vegetation species richness varies across sites with McCoy having the greatest diversity of species at 37 and V1 having the least at 10 species (Figure 4). In order to calculate the dominant species in each zone at each site by percent cover, only the most recent data collected in 2016 were used. The full results for fall 2016 can be found in Appendix A and the full results for spring 2016 are in Appendix B.

The dominant species by cover varied among sites and among marsh zones and even by season. For example, in the fall *Frankenia salina* dominates the upland of V4 with more than 80 percent cover and the mid marsh of McCoy with 42 percent cover, but it accounts for less than 20 percent cover everywhere else. However, in the spring *F. salina* dominates both the upland and high marsh of V4 with 78 and 64 percent cover respectively, and co-dominates the mid marsh of V1 with 45 percent cover.

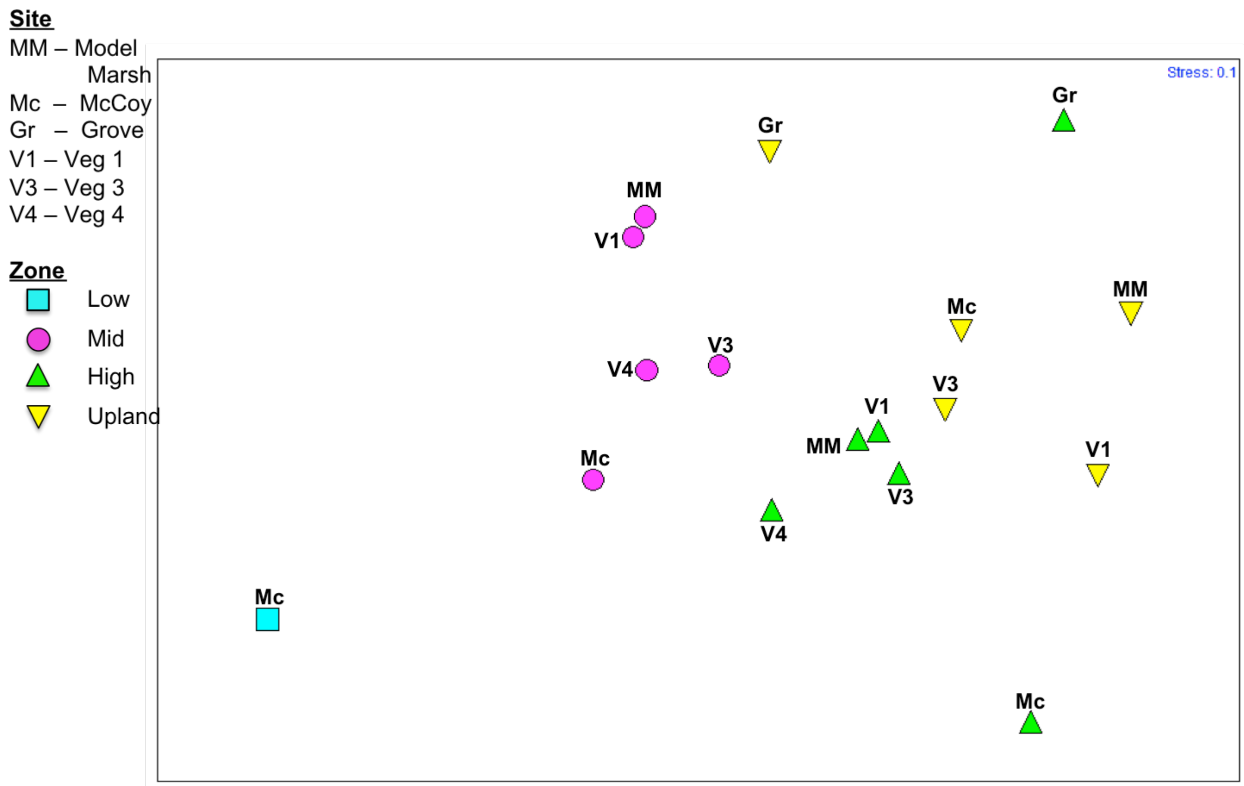

Figure 9. Non-metric multidimensional scale analysis of vegetation presence and average percent cover between the marsh zones of each site.

Non-metric Multidimensional Scale Analysis

Non-metric multidimensional scale analysis plots provide a visual representation of the relationships among a set of samples. This plot represents the similarity between the marsh zones and their relationships to each other across the sites. Specifically, this plot evaluates the species composition of the zones at each site by percent cover. The closer two points sit together, the more similar the species composition between them.

Analysis of the relationships between marsh zones shows that each zone tends to cluster together. For example, the five sites that run through the mid marsh are all grouped relatively near each other, which indicates a similarity among the species and their percent cover in that zone across all the sites. This also occurs with four of the six sites that run through the high marsh, V4, Model Marsh, V1 and V3. These sites cluster together even more tightly than the mid marsh group, indicating a closer relationship among the sites. The high marsh zone in McCoy and Grove are exceptions, and their locations in the opposite corners on the right side indicate the species found at each are different than rest of the sites' high marsh zone. There is only one low marsh zone across all six sites, but the location of McCoy low marsh in the lower left corner, away from any other zones, demonstrates that it is the most distinct. Of all the zones, the high marsh seems to be the most variable and is scattered across the right side of the plot.

Species Elevation Distribution

Based on the results of the percent cover plots (Appendix A,B), twelve species were selected for further analysis: *Spartina foliosa, Salicornia pacifica, Jaumea carnosa, Limonium californicum, Distichlis littoralis, Frankenia salina, Cressa truxillensis, Arthrocnemum subterminale, Lycium californicum, Glebionis coronaria, Mesembryanthemum crystallinum,* and *Mesembryanthemum nodiflorum*. These species were selected based one or more factors, such as frequency of appearance across sites, dominance of percent cover, importance to the southern California salt marsh ecosystem or because they are prominent upland non-natives that need to be closely monitored. The elevation distribution for each species at each site for the year 2016 was plotted. Lines delineating the Zedler and Cox (1985) habitat breaks are included for reference. Species were also selected to roughly represent the different marsh zones and have been displayed in groups of similar elevation ranges in order to better compare their distribution.

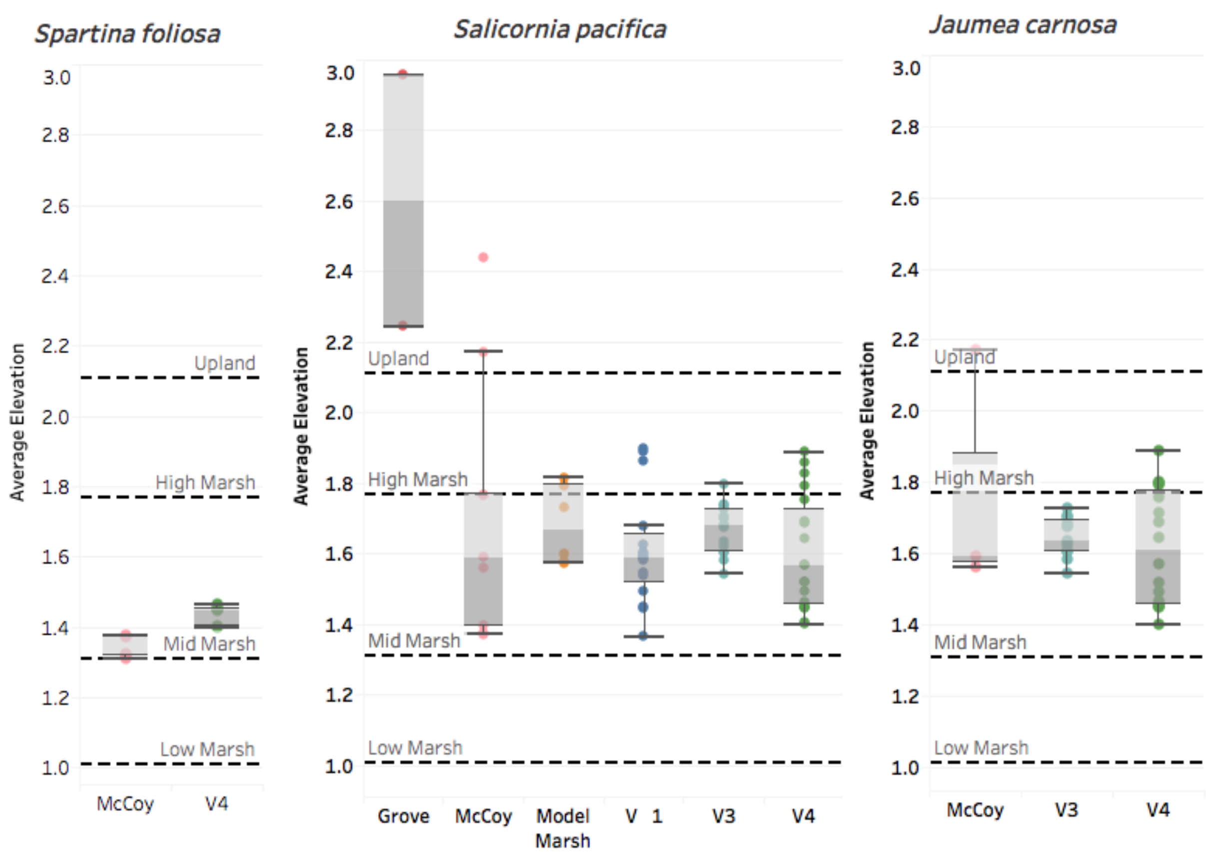

Figure 5. Elevation distribution between sites for Spartina foliosa, Salicornia pacifica and Jaumea carnosa. These species are commonly found in the low to mid marsh zones.

Spartina foliosa, Salicornia pacifica and *Jaumea carnosa* have been displayed together because they typically occupy the low to mid marsh zones. *S. foliosa* in particular is the dominant plant in the lowest areas of the marsh, and was found at two sites at the TRNERR. Although only McCoy reaches the low marsh, *S. foliosa* is distributed to the lowest range at that site (Figure 5). At V4, *S. foliosa* is distributed exclusively in the mid marsh, although it should be noted that this is within the lowest portion of the elevation range for that site. *S. pacifica* is found at all six sites at varying elevations (Figure 5). At V1, V3, V4 and McCoy more than 75 percent of the occurrences are within the mid marsh. At Grove *S. pacifica* is found only in the upland zone. *J. carnosa* is found at three sites, with a majority of the occurrences in the mid marsh (Figure 5). It is found only in the mid marsh at V3, but is found from the mid marsh to the high marsh at V4 and from the mid marsh to the upland at McCoy.

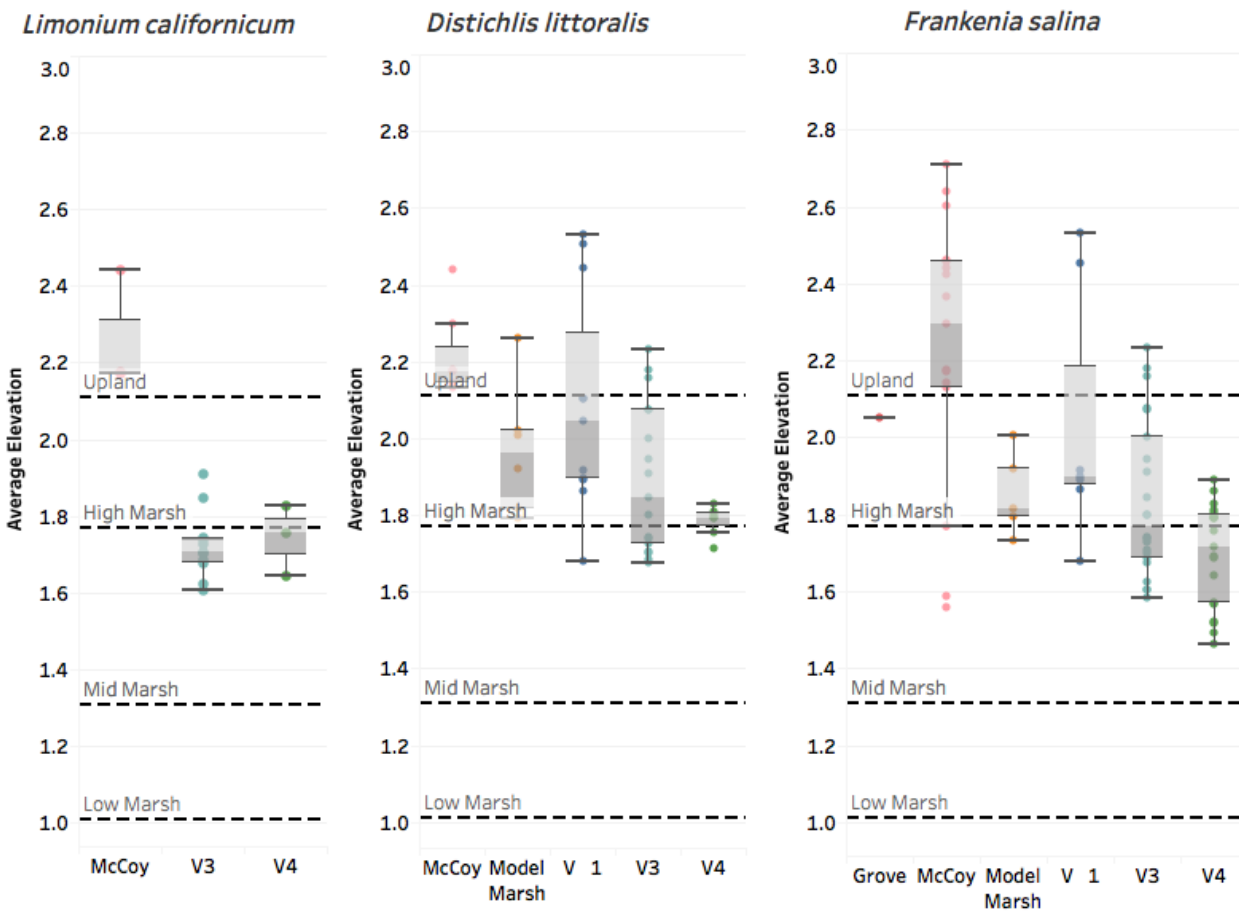

Figure 6. Elevation distribution between sites for Limonium californicum, Distichlis littoralis and Frankenia salina. These species are commonly found in the mid to high marsh zones.

Limonium californicum, Distichlis littoralis and *Frankenia salina* are displayed together because they are usually found in the mid to high marsh zones. *Limonium californicum* occurs at three sites, with majority of those occurrences at V3 and V4 in the mid marsh zone (Figure 6). At McCoy, *Limonium californicum* is found in only the upland zone. *Distichlis littoralis* is found at all sites but Grove, with more than 50 percent of the occurrences in the high marsh at Model Marsh and V4 (Figure 6). It is found only in the upland zone at McCoy. *F. salina* is found across all the sites, and its distribution varies from the mid marsh to the upland (Figure 6). At V3 and V4 it occurs all or mostly in the mid and high marsh, at Model Marsh and V1 the majority of occurrences are in the high marsh, and at McCoy it is mostly found in the upland. *F. salina* was only found once at Grove in the high marsh.

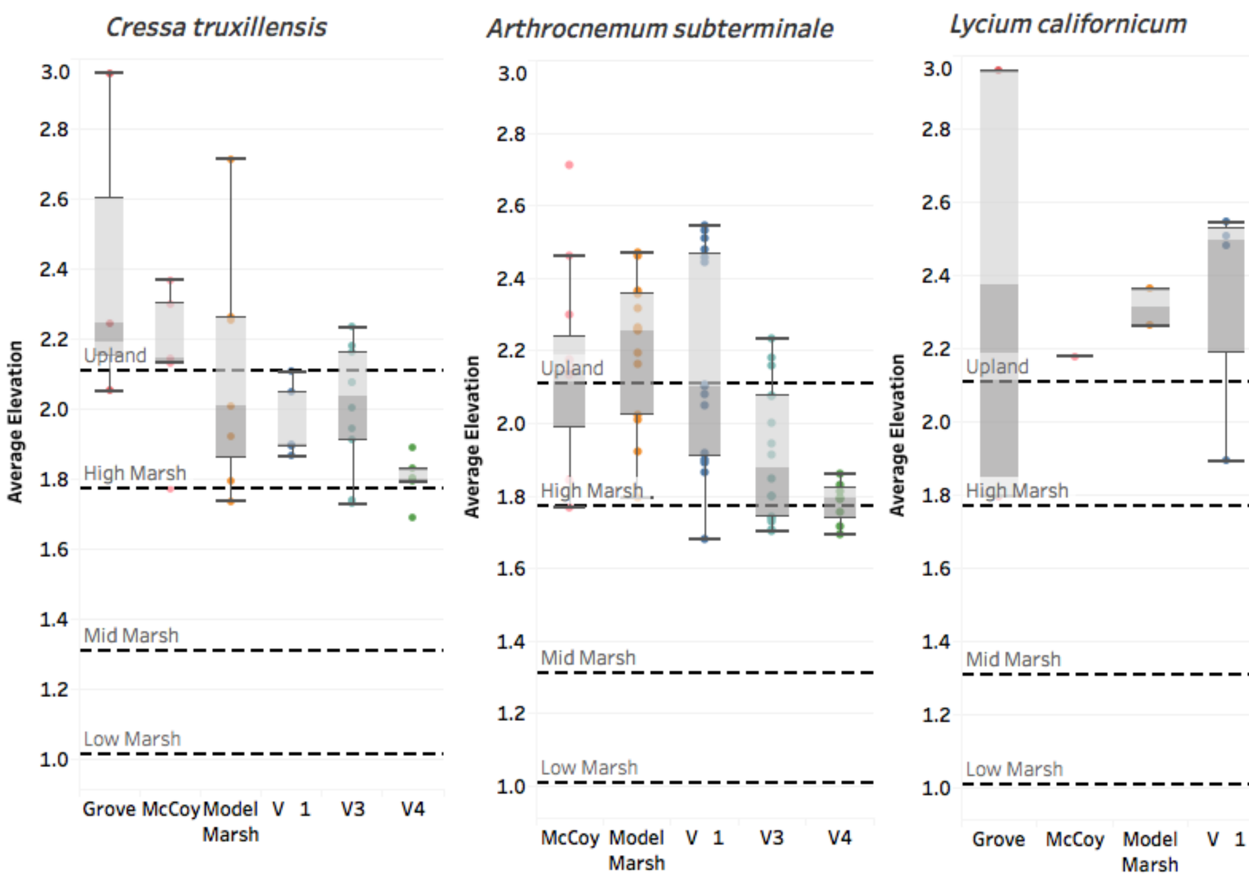

Figure 7. Elevation distribution between sites for Cressa truxillensis, Arthrocnemum subterminale and Lycium californicum. These species are commonly found in the mid to high marsh zones.

Cressa truxillensis, Arthrocnemum subterminale and *Lycium californicum* are also typically found in the mid and high marsh zone, although they tend to occur at slightly higher elevations than the previous group. *C. truxillensis* occurs at all sites at the TRNERR (Figure 7). At V1 and V4 it was found in the high marsh more than 75 percent of the time. At Grove, McCoy and Model Marsh *C. truxillensis* is found in the upland more than 50 percent of the time and at V3 it is distributed more evenly from the mid marsh to the upland. *A. subterminale* is found everywhere except Grove, and at V3 and V4 it is distributed mainly in the high marsh (Figure 7). At V1 it is distributed more evenly from the mid marsh to the upland and at McCoy and Model Marsh more than 50 percent of the occurrences are in the upland. *Lycium californicum* occurs at four sites, although it is only found once in the upland at McCoy and twice at Model Marsh (Figure 7). At V1 and Grove it occurs more than 50 percent of the time in the upland.

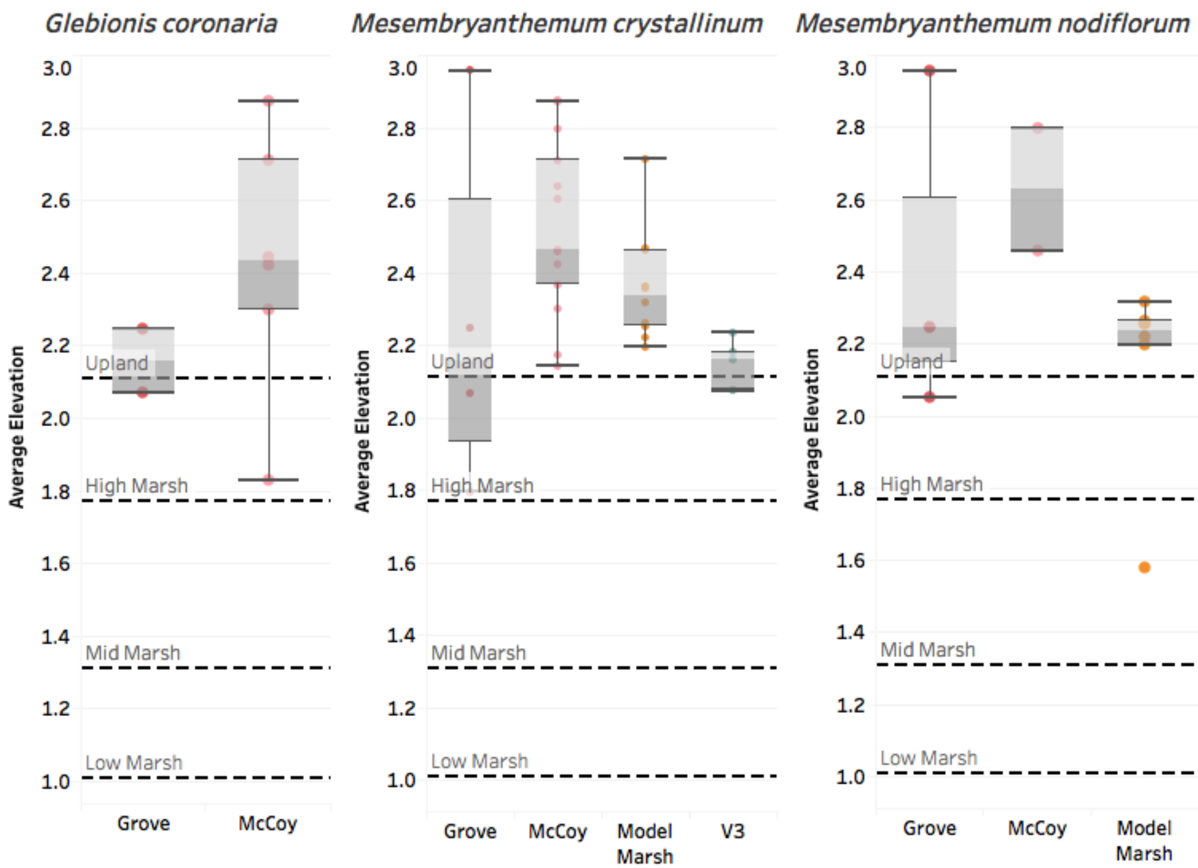

Figure 8. Elevation distribution between sites for Glebionis coronaria, Mesembryanthemum crystallinum and Mesembryanthemum nodiflorum. They are non-native species that are commonly found in the upland zone.

Glebionis coronaria, Mesembryanthemum crystallinum and *Mesembryanthemum nodiflorum* are non-native upland plants that have been selected as important species to monitor for invasion into native salt marsh habitat. *G. coronaria* is found at two sites, Grove and McCoy (Figure 8). At McCoy it is found almost exclusively in the upland, with the exception of one instance in the high marsh. At Grove it occurs once in the high marsh and once in the upland. *M. crystallinum* occurs at four sites in the TRNERR (Figure 8). It is found from the high marsh to the upland at Grove and V3. Elsewhere, it is found exclusively in the upland zone. *M. nodiflorum* is found at three sites, with one occurrence in the mid marsh at Model Marsh and one occurrence in the high marsh at Grove (Figure 8). Otherwise, it is found only in the upland zone, especially at McCoy where it is found entirely within that boundary.

IV. DISCUSSION AND RECOMMENDATIONS

Analysis of the vegetation database and elevation data reveals distinct patterns in the salt marsh plant community at the TRNERR. In general, the zones are distinguishable by species composition through MDS analysis. The low marsh has the most distinct species while the upland has the largest variety of species. Furthermore, the similarity between sites tends to decrease as elevation increases. Although the Zedler and Cox (1985) habitat breaks manage to explain the differences in plant composition due to elevation changes, there are still site-specific differences that could influence management and restoration. For example, the presence of *S. pacifica* in the high marsh at Grove but in the mid to high marsh at the other five sites (Figure 5) indicates that restoration of that species at Grove may need to occur further up slope than elsewhere on the Reserve.

Quality Control - Distinguishing Bare Ground and Litter

An issue that arose during the completion of this project was determining the parameters that distinguished bare ground and litter. I received a few different definitions for each from the scientists that collect the yearly transect data and even the methods used by the scientist to collect each variable were different. While it appears that the two were determined differently at times, I do not think that it greatly affected the outcome of this study. The amount of unvegetated ground remains the same whether it is classified as bare ground or litter. There is also an ongoing debate as to whether litter should be determined as a subset of bare ground or whether the two should be classified as completely separate. While determining the percent cover of plants in a quadrat is inherently subjective, determining set standards for the categories collected is necessary to reduce error between samplings as much as possible. Another solution is to group the two together and have one category for unvegetated ground.

Effectiveness of Current Habitat Breaks and Recommended Species for Planting

Low Marsh

With only one site extending into the low marsh zone there is no way to compare the relationship between sites of this zone. However, the MDS analysis reveals that the species composition of McCoy low seems to be very different from the rest of the zones (Figure 9) and this is supported in past literature (Zedler 1977; Zedler and Nordby 1986). The percent cover data supports this, showing that *S. foliosa* is the only species found in this zone (Appendix A) besides bare ground, which was excluded from the MDS. *S. foliosa* dominates the low marsh, typically within the elevation range of 1.01 - 1.31 m (Zedler and Cox 1985), although in several instances it is found in the mid marsh at V4 and McCoy (Figure 5). Even though it can be found in higher marsh zones, it is recommended that *S. foliosa* be considered for revegetation in the low marsh, as that is where it is likely to do best (Zedler and Nordby 1986).

Mid Marsh

There seems to be a close relationship in the mid marsh zone across sites, which are grouped together in the MDS (Figure 9). The appearance of *S. pacifica* in the mid marsh at all five sites that extend into that zone (Grove does not reach the mid marsh) likely contributes to this result (Figure 6). This is further corroborated by the seasonal percent cover data, where *S. pacifica* is the dominant species in this zone at all sites but McCoy in the fall of 2016 (Appendix A). Past studies at the TRNERR have found similar elevation ranges for *S. pacifica* (Zedler and Nordby 1986; Uyeda et al. 2013). Its high abundance at the mid marsh across all sites within the TRNERR make *S. pacifica* a good species to include in salt marsh revegetation plans, although it may not be necessary to plant it. In the past it has readily recruited into the area after restoration efforts (Zedler and West, 2008). While its elevation range varies across sites and *S. pacifica* can be found as high as the upland in Grove, it is most dominant in the mid marsh and will likely do best within the 1.31 - 1.77 m range. Other species that appear to do well in this elevation range and should also be considered for revegetation efforts include *J. carnosa and F. salina*, which tend to be the second and third most dominant species by percent cover in the mid marsh behind *S. pacifica*.

High Marsh

In the high marsh four of the six sites - V1, V3, V4 and Model Marsh - are all very similar in species composition. This relationship is even more similar than the relationship between the mid marsh sites, as evidenced by the tighter cluster for this group. The exceptions are McCoy and Grove, which appear to have different species compositions from the rest of the high marsh sites and from each other (Figure 9). This is further supported by the elevation distributions for species through the high marsh zone. For example, species that appear at most of the sites, such as *A. subterminalis* or *D. littoralis,* tend to vary in their distribution. Either species tends to dominate the marsh zone at V1, V3, V4 and Model Marsh (Appendix A, B), but the dominant species at McCoy is either *G. coronaria* or *M. crystallinum*, while at Grove it is *D. spicata* or *M. crystallinum*, depending on the season (Appendix A, B). Other studies that have looked at the elevation distribution of species at the TRNERR have found similar ranges for *A. subterminalis* and *D. littoralis* (USGS 2014; USGS 2015). While both naturally occur from the mid marsh to the upland, it is recommended that they be planted in the high marsh zone between 1.77 - 2.11 m and then allowed to naturally expand their range from there.

Upland

The upland zone has the most irregular relationship of the marsh zones, with the five sites (V4 does not reach into the upland) scattered on the MDS plot more widely than any of the other zones (Figure 9). Given the number of species that are typically found in this zone, both salt marsh and terrestrial, the dissimilarity among the sites is understandable. Elevation distribution plots for the selected species show that the distribution of many of the species, even those that typically occupy the mid or high marsh, varies from site to site (Figures 5,6,7). For example, *Limonium californicum*, a typical mid marsh species, is found only in the upland zone of McCoy, while at V3 and V4 it is found in the lower marsh zones (Figure 6). Differences in species distribution across sites may be due to a number of different factors such as differences in salinity, plant facilitation or plant competition. Even small differences in the micro-topography of a site could result in some sections of that site remaining inundated longer, resulting in a different species composition.

Invasive Species

G. coronaria, M. crystallinum and *M. nodiflorum* were all included in the group of species selected for elevation distribution plots because they are prominent non-native species at TRNERR. Of the six sites, Grove seems to be the most impacted by the selected non-native species, with *G. coronaria* and *M. crystallinum* extending down into the high marsh. Further monitoring of invasive species is important to track changes in their distribution over time, especially when it comes to restoration efforts in the high marsh area. The restoration of areas invaded with non-native species will require more time, effort and resources in order to control their spread than in lower areas of the marsh where such measures are not required.

Sea Level Rise Indicator Species

One goal of this study was to use the information gathered to find species that can be monitored into the future to serve as indicators for marsh migration due to sea level rise. Some characteristics I used for a good indicator species include:

- one that is common, so that it can serve as an indicator for the entire reserve
- easy to identify, in order to simplify monitoring and allow more rapid assessments
- has a discrete upper or lower boundary that tends to be consistent across sites, so that changes in this boundary can be used to track changes in sea level rise

Of the twelve species whose elevation distributions were plotted, one species, *Arthrocnemum subterminale*, fits the characteristics described. The species is commonly found across the TRNERR and is found at five of the six vegetation monitoring sites (Grove being the exception). It is also easy to identify in the field and is one of the more ubiquitous marsh species in southern California. Finally, it is also tightly bound to the mid to high marsh boundary line (Figure 7). Tracking changes in the distribution of *A. subterminale* will likewise reveal shifts in distribution of the mid to high marsh margin.

It is recommended that *A. subterminale* be monitored closely into the future as an indicator species. In addition to being monitored within the current transect system, which includes the monitoring of fixed quadrats, further monitoring approaches should be taken to mark the upper and lower limits of *A. subterminale* outside of the quadrats. This will allow changes in distribution to be caught before they hit the quadrats. The full extent of the distribution of this species at the survey site should be recorded by GPS during each survey season in order to get a more detailed distribution profile. Detection through remote sensing should also be considered.

V. CONCLUSION

Vegetation monitoring at the TRNERR is useful and necessary and should be continued. This analysis of the current vegetation monitoring database has helped to define the salt marsh plant community by establishing benchmarks for the distribution of species across the elevation gradient. One useful application of this study will be the use of this data and these monitoring sites as reference sites for future restoration efforts. Knowing the differences in distribution of species across sites will enable more effective restoration because the amount a time and resources used to plant species where they can be successful can be reduced. In addition, this study identified *A. subterminale* as an indicator species that can be used to track changes within the Reserve due to sea level rise. Moving into Phase II of the TETRP and even looking beyond, monitoring will be necessary in order to continue applying the principles of adaptive management and ensure the long-term success of salt marsh ecosystems on the Reserve.

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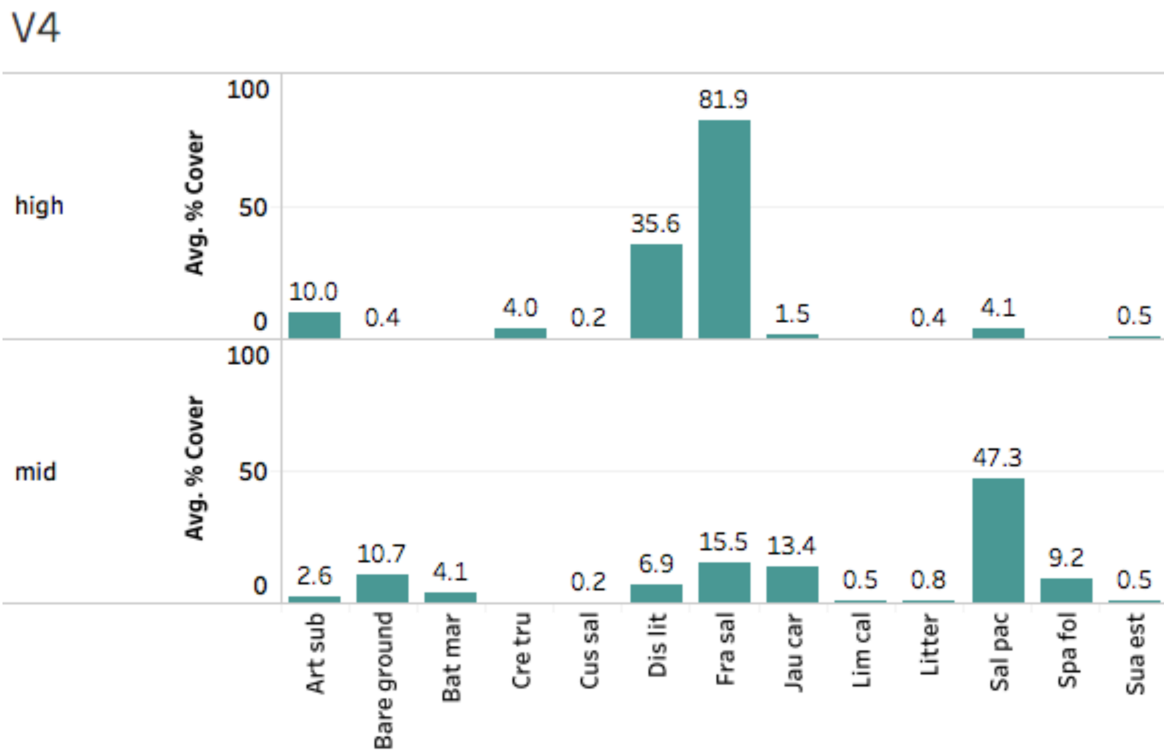
APPENDICIES

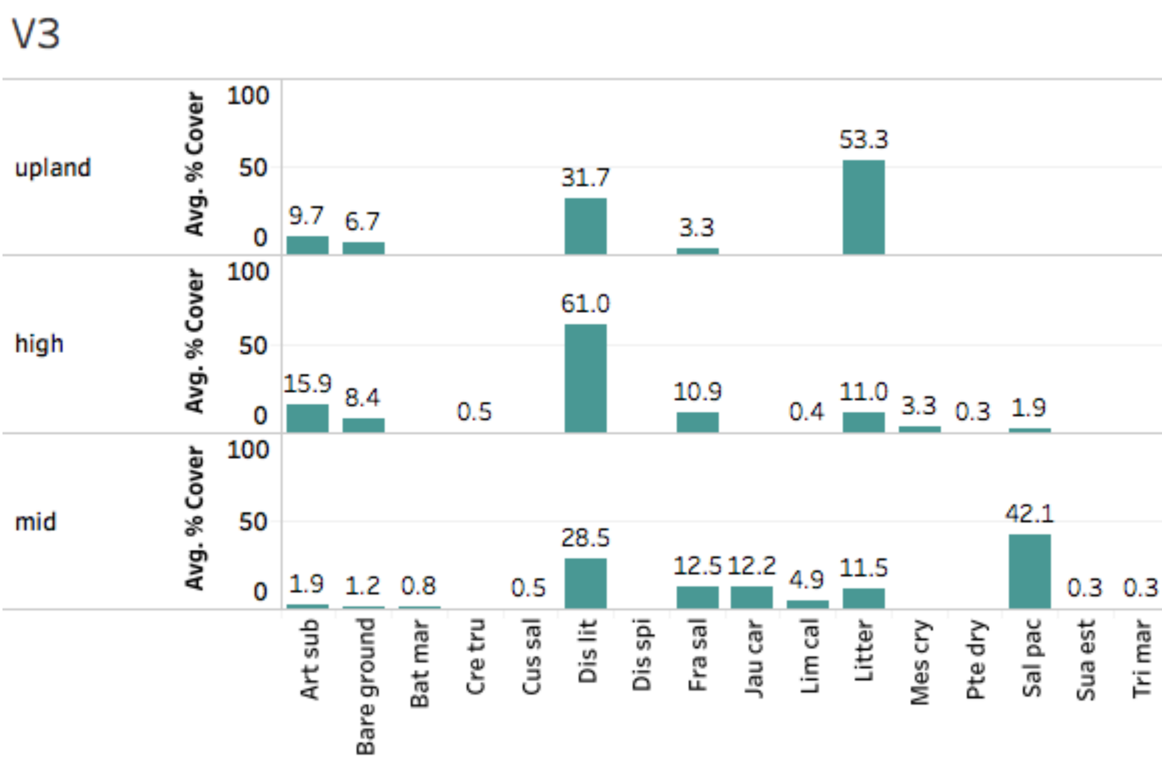
Species in the following appendices have been shortened using the following abbreviations:

Abbreviation	Scientific Name	Common Name
Amb pus	*Amblypappus pusillus*	Pineapple weed
Ant nut	*Antirrhinum nuttallianum*	Nuttall's snapdragon
Art sub	*Arthrocnemum subterminale*	Parish's glasswort
Atr sem	*Atriplex semibaccata*	Australian saltbush
Bas hys	*Bassia hyssopifolia*	Five horn smotherweed
Bat mar	*Batis maritime*	Saltwort
Bro mad	*Bromus madritensis*	Foxtail brome
Cre tru	*Cressa truxillensis*	Alkali weed
Cus sal	*Cuscuta salina*	Salt marsh dodder
Dis lit	*Distichlis littoralis*	Shore grass
Dis spi	*Distichlis spicata*	Salt grass
Eri fas	*Eriogonum fasciculatum*	California buckwheat
Ero cic	*Erodium cicutarium*	Red stemmed filaree
Fra sal	*Frankenia salina*	Alkali heath
Gle cor	*Glebionis coronaria*	Crown daisy
Hor mur	*Hordeum murinum ssp. Leporinum*	Farmer's foxtail
Hor pro	*Hornungia procumbens*	Slenderweed
Jau car	*Jaumea carnosa*	Fleshy Jaumea
Lim cal	*Limonium californicum*	California sea lavender
Lyc cal	*Lycium californicum*	California boxthorn
Mal par	*Malva parviflora*	Cheeseweed mallow
Mel off	*Melilotus officinalis*	Annual yellow sweetclover
Mes cry	*Mesembryanthemum crystallinum*	Crystalline iceplant
Mes nod	*Mesembryanthemum nodiflorum*	Slender leaved iceplant
Oxa pes	*Oxalis pes-caprae*	Sourgrass
Par inc	*Parapholis incurva*	Curved sicklegrass
Pte dry	*Pterostegia drymarioides*	Fairy mist
Sal pac	*Salicornia pacifica*	Pickleweed
Son ole	*Sonchus oleraceus*	Common sow thistle
Spa fol	*Spartina foliosa*	California cordgrass
Sua est	*Suaeda esteroa*	Estuary seablite
Tri mar	*Triglochin maritima*	Seaside arrowgrass

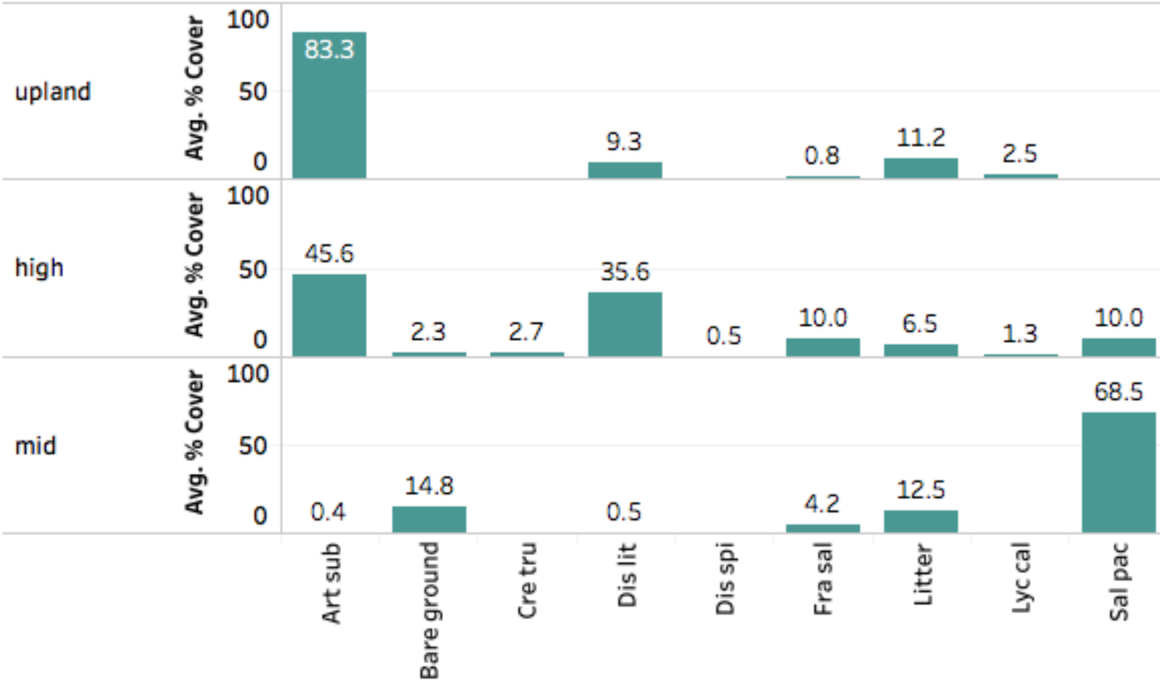
Appendix A.

Fall 2016 Species Percent Cover

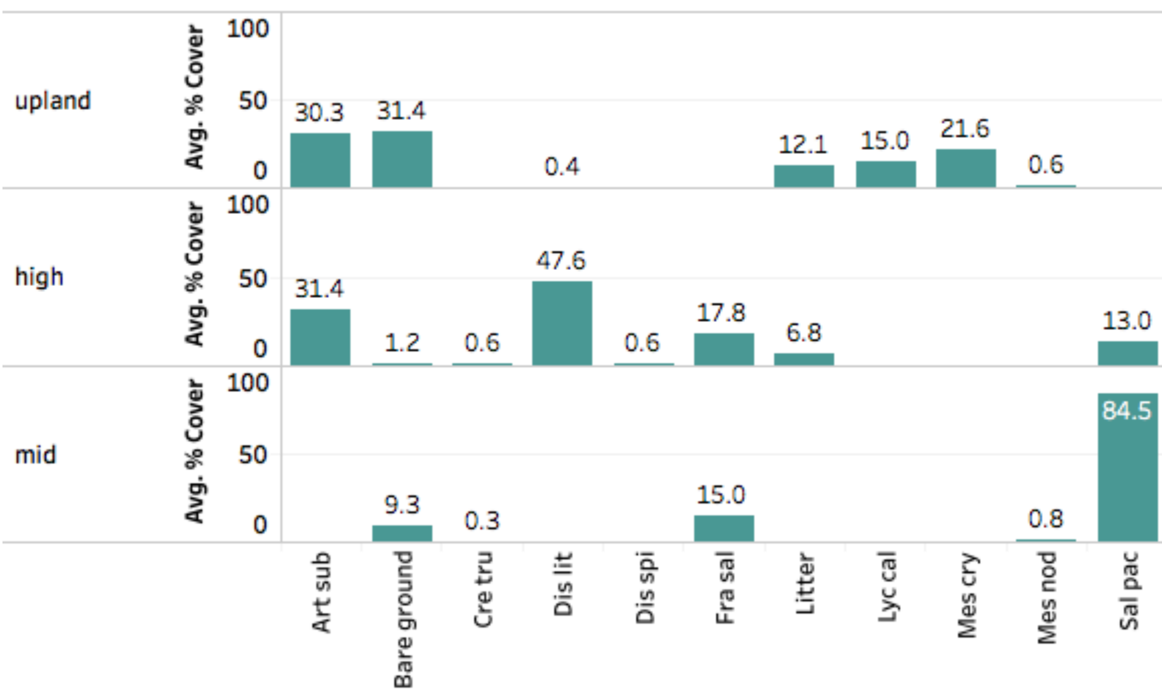




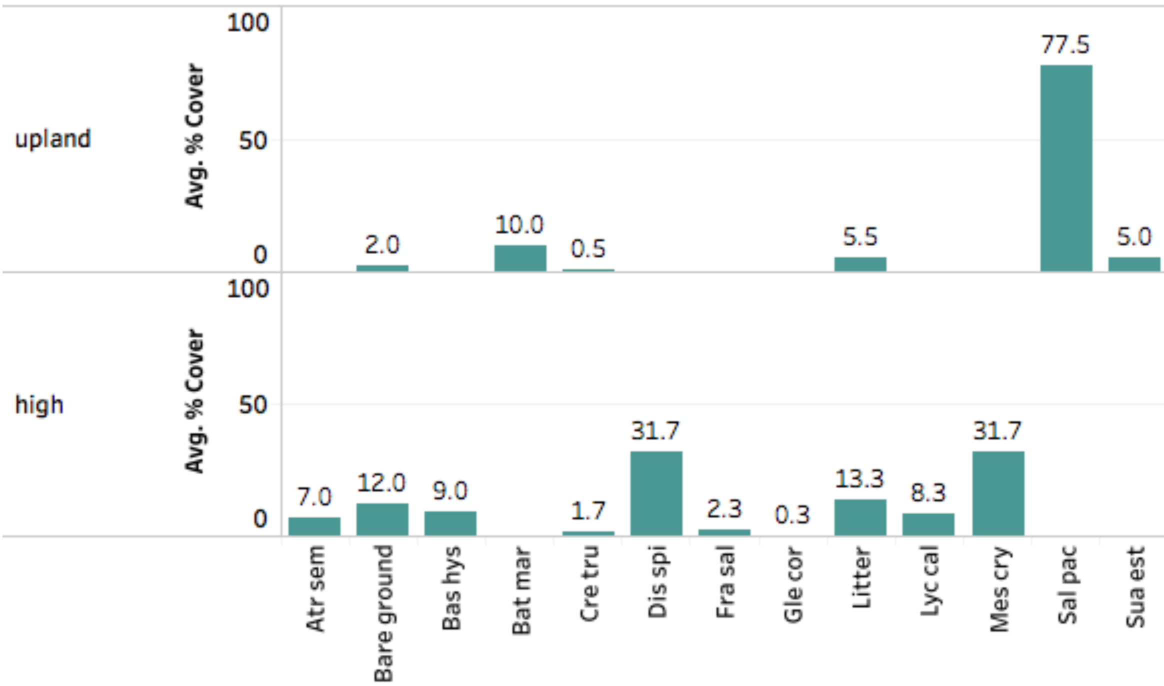
V 1



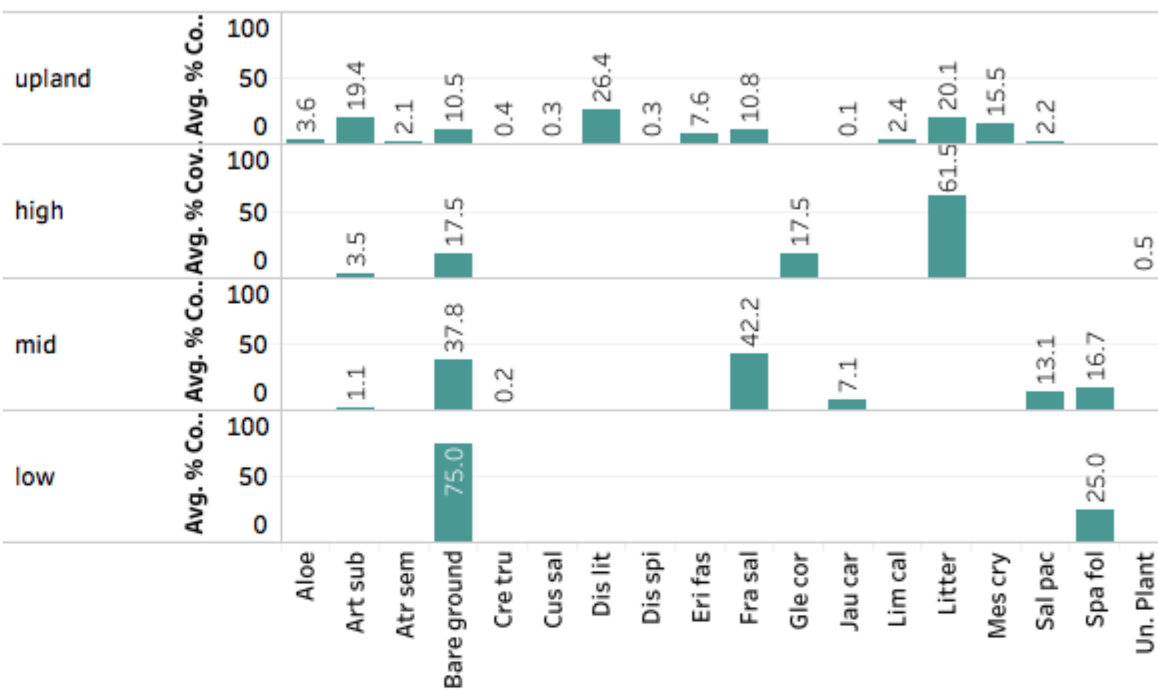
Model Marsh



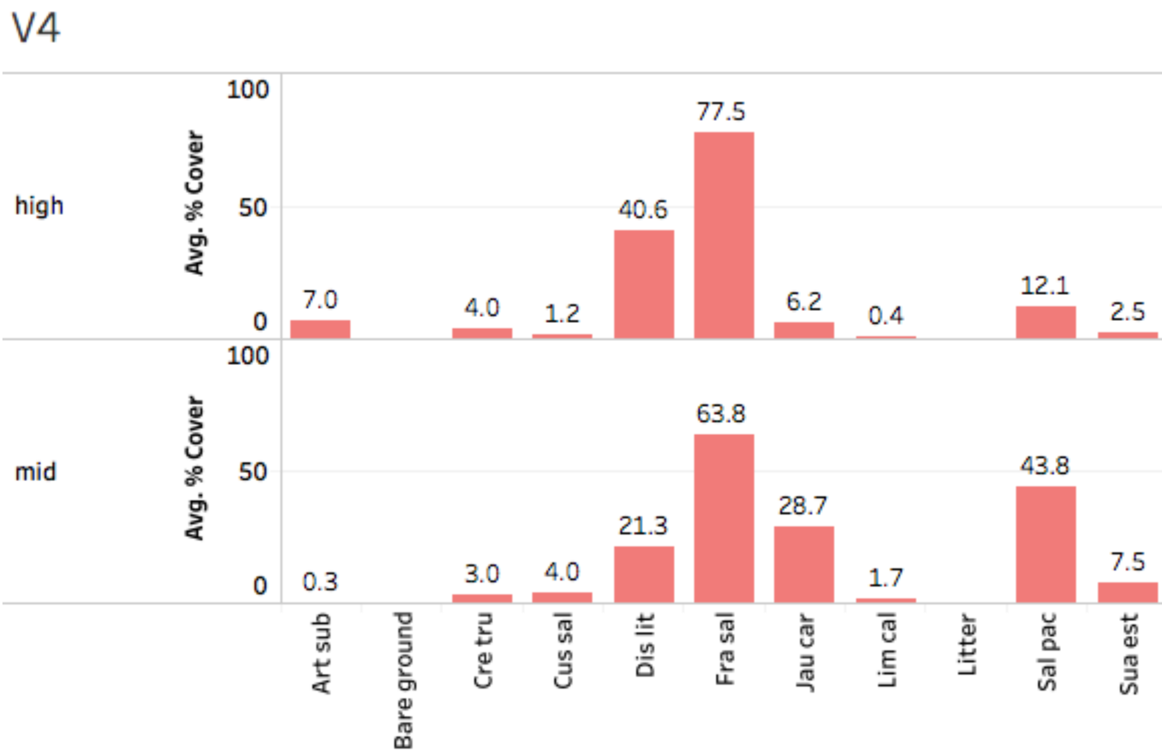
Grove

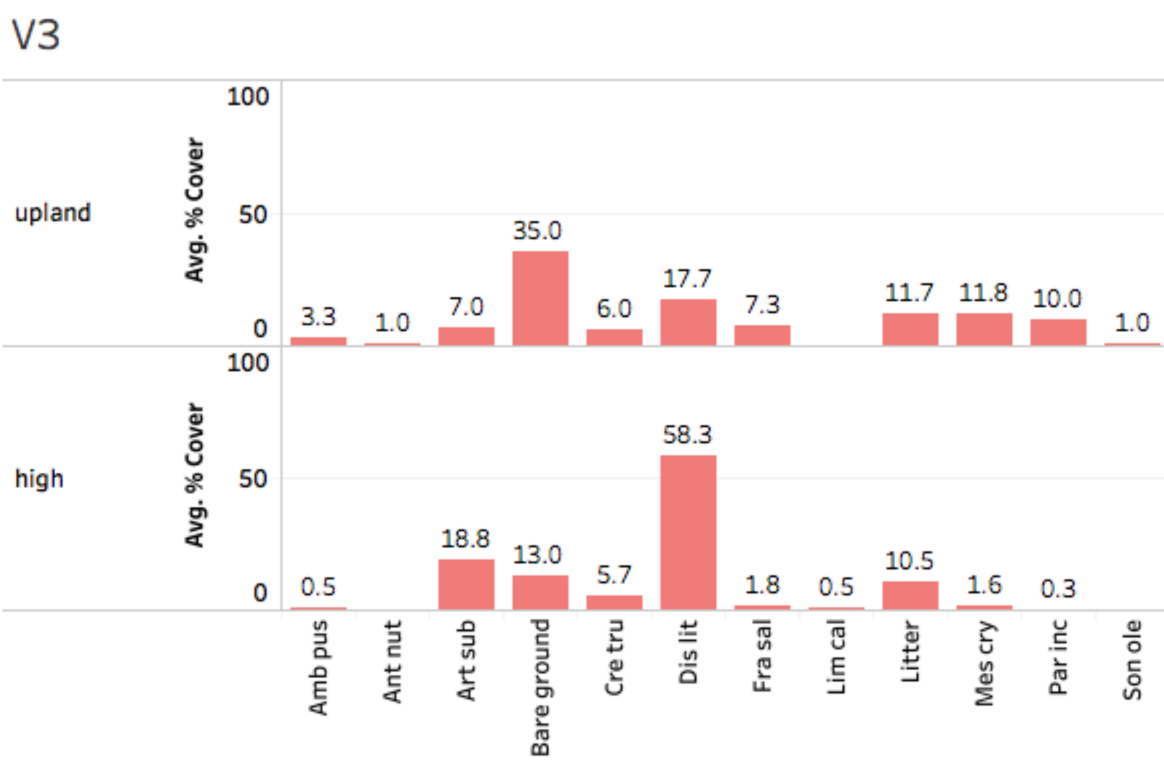

upland
high
Avg. % Cover
100
50
0
77.5
2.0
10.0
0.5
5.5
5.0
31.7
31.7
7.0
12.0
9.0
1.7
2.3
0.3
13.3
8.3
Atr sem
Bare ground
Bas hys
Bat mar
Cre tru
Dis spi
Fra sal
Gle cor
Litter
Lyc cal
Mes cry
Sal pac
Sua est

McCoy

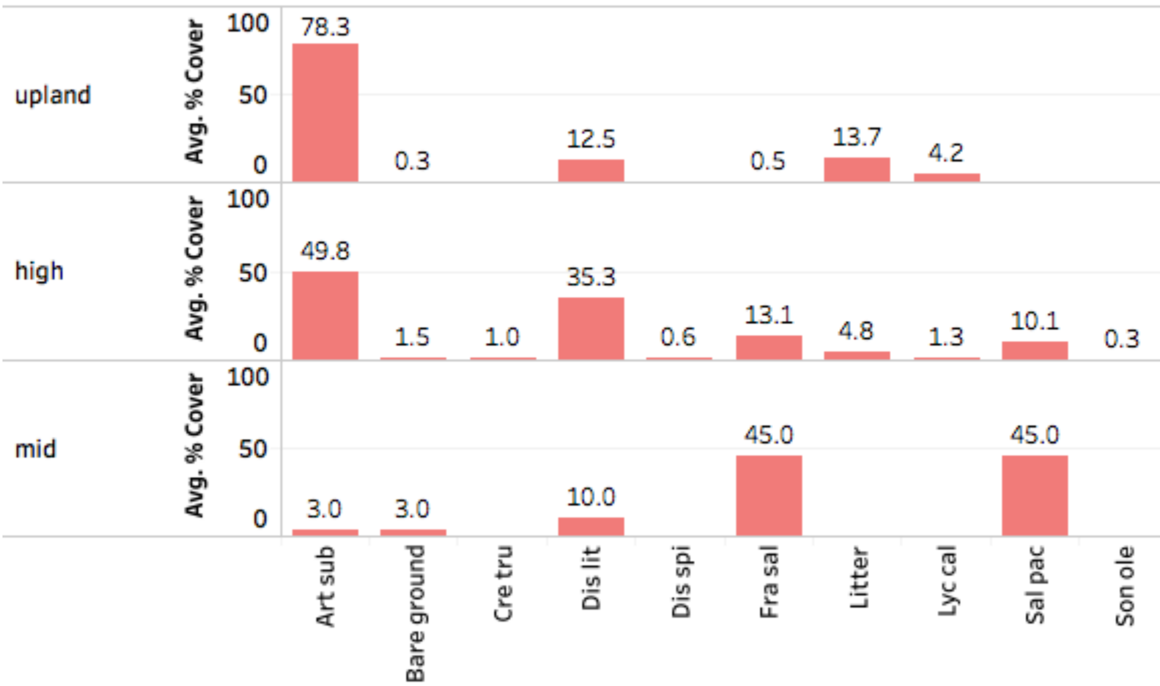

upland
high
mid
low
Avg. % Co..
Avg. % Cov..
Avg. % Co..
Avg. % Co..
100
50
0
3.6
19.4
2.1
10.5
0.4
0.3
26.4
0.3
7.6
10.8
0.1
2.4
20.1
15.5
2.2
3.5
17.5
17.5
61.5
0.5
1.1
37.8
0.2
42.2
7.1
13.1
16.7
75.0
25.0
Aloe
Art sub
Atr sem
Bare ground
Cre tru
Cus sal
Dis lit
Dis spi
Eri fas
Fra sal
Gle cor
Jau car
Lim cal
Litter
Mes cry
Sal pac
Spa fol
Un. Plant

Appendix B.
Spring 2016 Species Percent Cover

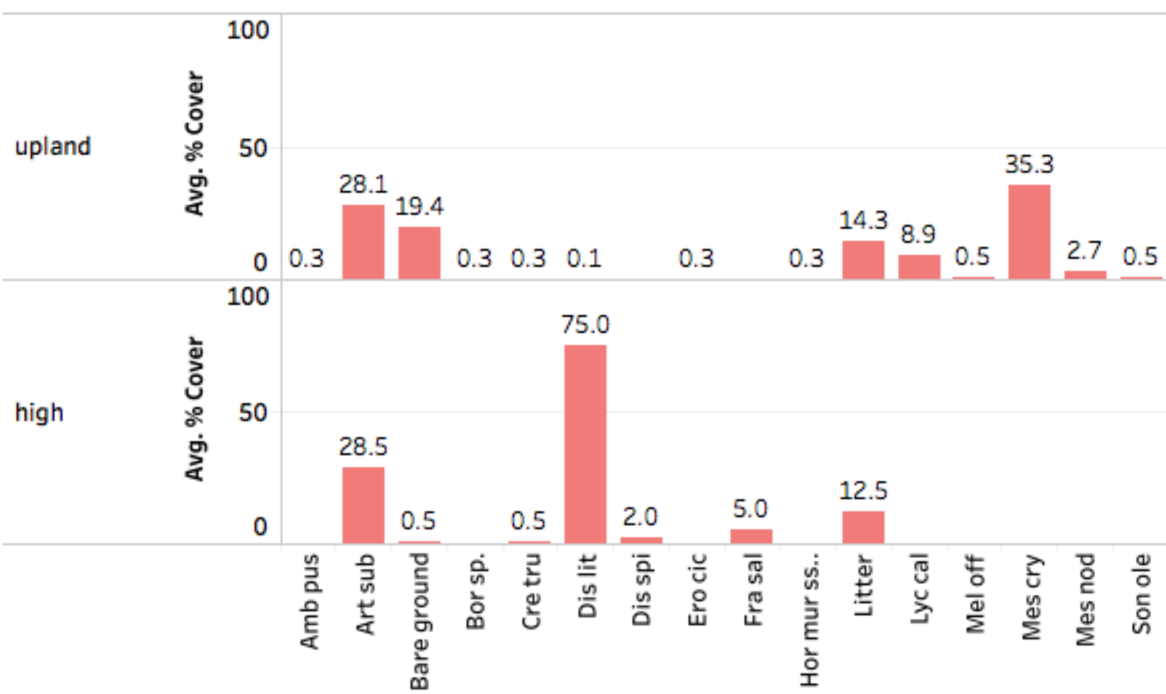


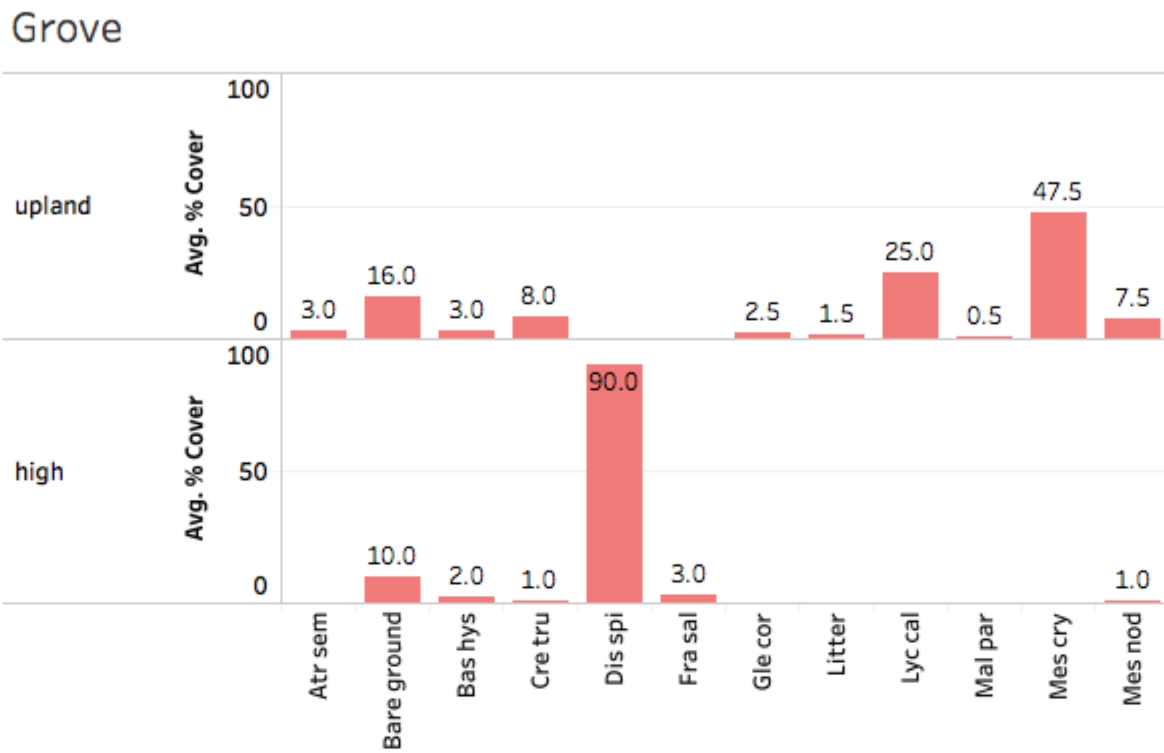


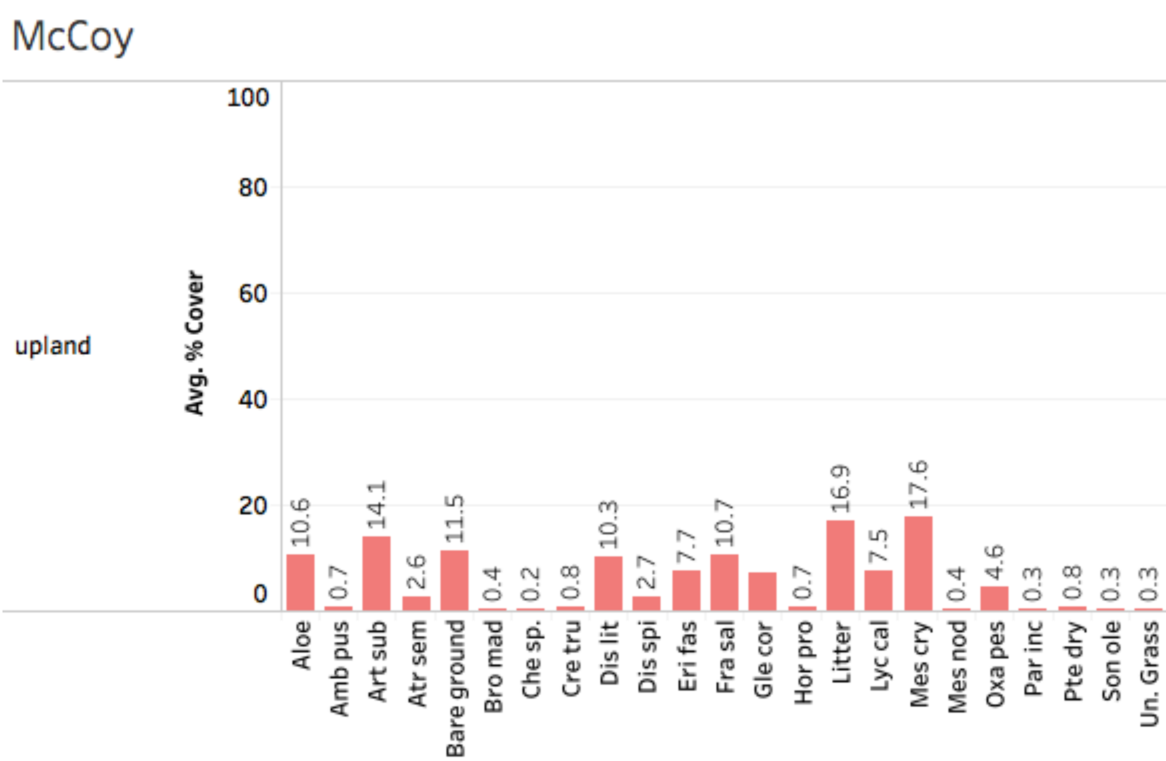
V 1



Model Marsh




Grove
upland
high
Avg. % Cover
100
50
0
3.0
16.0
3.0
8.0
2.5
1.5
25.0
0.5
47.5
7.5
90.0
10.0
2.0
1.0
3.0
1.0
Atr sem
Bare ground
Bas hys
Cre tru
Dis spi
Fra sal
Gle cor
Litter
Lyc cal
Mal par
Mes cry
Mes nod


McCoy
upland
Avg. % Cover
100
80
60
40
20
0
10.6
0.7
14.1
2.6
11.5
0.4
0.2
0.8
10.3
2.7
7.7
10.7
0.7
16.9
7.5
17.6
0.4
4.6
0.3
0.8
0.3
0.3
Aloe
Amb pus
Art sub
Atr sem
Bare ground
Bro mad
Che sp.
Cre tru
Dis lit
Dis spi
Eri fas
Fra sal
Gle cor
Hor pro
Litter
Lyc cal
Mes cry
Mes nod
Oxa pes
Par inc
Pte dry
Son ole
Un. Grass