ANALYSIS OF THE IMPORTANCE OF MARSH AGE, PLANT COMMUNITY AND SEDIMENT PROPERTIES ON THE RECOVERY OF AN URBANIZED WETLAND'S INVERTEBRATE COMMUNITY

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I, THE UNDERSIGNED MEMBER OF THE COMMITTEE,

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ABSTRACT

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With the loss of approximately 90% of historical wetlands, the impacts of their loss are now being realized. As such, we are moving into a time where we must learn how to develop restorations plans that find methods which allow wild ecosystems to flourish in highly urbanized locations. The Colorado Lagoon is an urbanized, saltwater marsh in Southern California where sediment cores were collected to perform tests on grain size, organic matter, microalgae through Chlorophyll a, and water content, and determine how those parameters correlate with marsh age since restoration, invertebrate communities, and plant cover. I found that total plant cover, plant richness, and invertebrate abundance and diversity increased with restoration age. This supports the idea that plant cover plays a vital role in wetland recovery. More research should be conducted in urbanized, saltwater marshes and active planting in order to improve the recovery of these unique ecosystems.

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CHAPTER 1

INTRODUCTION

A tidal wetland is an ecosystem where salt water saturates the soil, leading to the development of characteristic soil and specifically adapted organisms (EPA, n.d.). These natural systems filter water, sequester carbon, provide flood and erosion control, and supply food and habitat for fish and wildlife (Chmura et al., 2003; Zhang et al., 2010; NOAA, n.d.). However, due to the consequences of climate change, sea-level rise, urbanization, and coastal degradation (USFW, 1977; Kirwin et al., 2010), there has been extensive loss of coastal wetlands in California (Levin & Talley, 1999) at approximately 75% loss of historical wetland area (SCCWRP, 2014).

One strategy to deal with this loss of wetlands is restoration; these projects are designed to bring the ecosystem back to a desired baseline that reflects a more biodiverse, less impacted environment. While restoration does work in returning the wetland back to this baseline, the process can take some time, and for salt marshes it can often take anywhere between 8 to 10 years post-restoration to see this improvement (e.g. Levin & Talley, 1999). Thus, it is important to understand how time since restoration (i.e. marsh age) influences the distribution and types of plant and animal communities that exist in restored sites.

In saltwater marshes, an important method for understanding how a marsh may be recovering post-restoration is comparing the age of the marsh since restoration and other key parameters, like plant cover and sediment type. Marsh age is often an indicator of the presence or absence of species over a large space and time scale, and microalgae amounts, sediment organic matter and grain size have been studied to understand how they influence total macrofaunal densities in a system (Levin & Talley, 2000). Understanding the macrofaunal and macroinvertebrate communities found in the system is important because they function as important food web indicators and can further indicate the stage of the recovery process based on older wetland recovery studies. With an improved understanding of what controls restoration trajectory and recovery, managers and scientists can better design restoration projects and alter ongoing restorations to improve the recovery of the invertebrate community within the marsh via these factors.

For this project, I collected data from the Colorado Lagoon, an urbanized lagoon in Long Beach, California, where there are three areas of different restoration age – the eastern arm being natural marsh, the western arm being approximately 10-years old, and the northern arm being newly restored in early 2017. The Colorado Lagoon presents a unique opportunity to compare the results of marsh age, plant cover, and sediment type within an urbanized lagoon.

My study aims to (1) analyze how differences in marsh age since restoration; correlate with plant cover, food sources (like microalgae), sediment organic matter, grain size, and invertebrate communities among the eastern, western, and northern arms of the Colorado Lagoon, (2) increase the understanding of the restoration process in an urban wetland, and (3) describe potential mechanisms that control the outcomes of post-restoration.

Hypotheses

This research project hypothesizes that the natural marsh (eastern arm) will have the highest abundance of tubificid and enchytraeid oligochaetes which are known to dominate older and natural marshes (Levin & Talley, 1999). This is most likely due to these areas containing organic rich, moist soils, so it likely enhances vascular plant production (Levin & Talley, 1999) which, in turn, the plant detritus and live roots beneath the thinner sediment may provide food and protection for these deposit-feeders (Levin & Talley, 1999). Thus, I also expect to find lower microalgae (through Chlorophyll a) due to less sunlight in planted, shaded areas, and lower percent sand in the sediments of the northern arm. Finally, the plant community will have the highest percent total plant cover as compared to other sections – although many of these species are expected to be non-native.

In the northern arm, which is the beginning stages of recovery, I expect to see a sparse, and low-diversity assembly of opportunist invertebrate species including insect larvae and terrestrial isopods (Levin & Talley, 2000) due to this not being a well-developed area, therefore the newly planted resources will be available to them before sediment and plant cover shifts influence it. In addition, I expect to find low total plant cover, low sediment organic matter, high Chlorophyll a due to the area being lightly vegetated, and high percent sand content relative to the other older areas of the lagoon.

In the western arm, I expect to see a higher abundance of invertebrate species relative to the northern arm but a lower abundance than the eastern arm. This could be an indicator that the marsh in this area will have less insect invertebrates and more of the deposit-feeding invertebrates mentioned earlier (Levin & Talley, 2002). With the marsh being approximately 10-years old, there is the possibility that the conditions there could strongly resemble that of the natural marsh, but the progress of recovery can be greatly affected by the urbanization in the surrounding area. Furthermore, I expect to see a higher total cover and abundance of plant species than in the northern arm, as well as higher percent organic matter, and lower percent sand content and Chlorophyll a, than in the northern arm. Overall, I expect to see a restoration trajectory that reflects marsh age and development of the plant community, with more plant cover and higher abundance of organisms in the older marshes. In addition, I expect higher organic matter will lead to a more diverse community of invertebrates. This would lead to a recommendation for planting marshes early in restoration to ensure that organic matter can develop in the soil and lead to faster restoration success.

CHAPTER 2

METHODS

Study Site

The Colorado Lagoon, located in Long Beach, California, is where I conducted my study. Historically, the area is a natural wetland ecosystem that once had a direct connection – thus tidal flow – to the ocean via Alamitos Bay. Due to the Los Angeles Summer Olympics of 1932, that direct connection to the ocean was severed when the city altered the land connecting the lagoon to Alamitos Bay to accommodate for the Olympic diving trials (FOCL, 2018). Through years of poor management, debris build-up, and increasing urbanization of the surrounding area, the lagoon rapidly degraded resulting in poor water quality and contamination of its sediment (FOCL, 2018). Since 2009, the lagoon has undergone multiple initiatives to restore it back to an ecosystem with full tidal influence, with its most recent project occurring in the Spring of 2017. For this most recent project, the Northern Beach was completely dredged and the shoreline "pushed back" to allow for a more optimal tidal flow through the lagoon, as well as the addition of numerous native plantings across the entire bank.

Currently, the lagoon is characterized as an urbanized, saltwater marsh that is connected to the ocean, but through a culvert channeling to Alamitos Bay. Due to the recent restoration at the Colorado Lagoon it provides the unique opportunity to compare the results of various marsh conditions of an urbanized lagoon at distinct stages of wetland recovery.

Sampling Methodology, Date, and Locations

The Colorado Lagoon is divided into three separate banks, or "arms," known as – the eastern, western, and northern banks. The eastern arm was restored 20 years ago, the western arm is approximately 10 years-old since restoration, and the northern arm is the youngest of arms being newly restored in April 2017. This means that the eastern arm should most resemble a natural marsh, the western arm should present a mid-way stage in wetland restoration trajectory, and the northern arm should represent the earliest stages in wetland restoration trajectory.

In November 2017, a round of sediment cores for grain size, organic matter, and chlorophyll A were collected from both the mid and low marsh at permanent, and pre-designated, transects, which were determined by a larger graduate study in the Wetland Ecology Lab (Figure 1). The sediment cores were collected on transects (transect number 1, 3, 6, 7, 9, 11, 13, 15, 17, 19, 23, 26, 32, 34, 36, 38, 41, and 43, n = 18 total) with a total of 36 total cores collected in 8.02cm^2 x 6 cm core cylinders. These sampling locations ensured that the entire site is covered, and that data taken from the associated study would be able to apply to my study. Once the samples were taken, they were taken back to the CSULB Wetland Ecology Lab to be frozen.

Grain Size, Organic Matter, Chlorophyll A, and Water Content

Grain size was determined in-lab utilizing the Hydrometer method (Bouycous, 1962) by diluting the samples in a 5% sodium metaphosphate solution and measuring over a 2-hour period the percent sand, silt, and clay. Organic matter was determined by finding the net weight of the sample lost on ignition, then calculating percent organic matter to sediment core. Chlorophyll a, taken because it is an important food source for some invertebrates, was determined utilizing the Chlorophyll a procedure (Plante-Cuny, 1973). Water Content was determined by measuring percent differences between the wet and dry sediment as it was prepared for the Chlorophyll a procedure.

Floral and Infauna Data

The floral and infauna data were collected through the associated graduate study. The benthic infauna samples were retrieved back in June 2017 for initial post-restoration analysis at the mid and low marsh areas of the 18 transects mentioned above. Invertebrate cores (8.02cm^2 x 6cm core cylinders) were taken as described above, and then returned to the laboratory to be preserved in 8% buffered formalin with Rose Bengal stain. At a later date, each core was sieved on a 300um sieve and sorted for invertebrates on a dissecting microscope. All invertebrates were identified to the lowest taxonomic level possible and vouchered in ethanol for storage. During this same sampling period, vegetation cover was recorded at both zones of the permanent transect locations as a part of long-term post-restoration monitoring. Within each transect the plants were identified to species and given an approximate percent cover for that given species.

Statistical Analysis

I conducted a one-way ANOVA within each elevation – mid and low – among each the three arms around the marsh to analyze how percent cover of plants, sediment organic matter, sediment grain size, and invertebrate abundance and species richness vary with marsh age. There were no analyses that were done comparing the mid to the low marsh as these differences are well-known (e.g. Levin and Talley 2000) and not the goal of this study. Prior to any parametric analysis, the data were tested for normality and equal variance through the MiniTab software. If the data did not meet assumptions of normality and equal variance, then it would have undergone a log 10 transformation through the Excel software. In addition, I used multivariate tests (PERMANOVA) through PRIMER software to determine differences in invertebrate community composition.

CHAPTER 3

RESULTS

I determined that there were no significant differences in percent organic matter (mid: p=0.450, F=0.84; low: p=0.931, F=0.07) (Figure 2) percent sand (mid: p=0.194, F=1.84; low: p=0.476, F=0.78) (Figure 3), microalgae abundance as measured as Chlorophyll a (mid: p=0.203, F=1.77; low: p=0.162, F=2.06) (Figure 3), and water content (mid: p=0.639, F=0.46; low: p=0.205, F=1.76) (Figure 5) among the different sections of the lagoon. The northern arm was found to have significantly lower total plant cover (mid: p≤0.01, F=35.25; low: p≤0.01, F=1.53)) (Figure 6) and plant richness (mid: p≤0.01, F=25.19; low: p≤0.01, F=8.08) (Figure 7) as compared to the other two locations within the lagoon.

The three arms had similar invertebrate abundance (mid: p=0.108, F=3.12; low: p=0.641, F=0.478) (Figure 8), but mid-zone for the northern arm was notably lower in invertebrate richness at the 0.072 level (mid: p=0.072, F=3.93; low: p=0.589, F=0.57) (Figure 9) and diversity at the 0.075 level (mid: p=0.075, F=3.82; low: p=0.447, F=0.90) than the other two locations (Figure 10).

In terms of the invertebrate community structure (Figures 11, 12), the eastern and the western arms were more similar to one another than to the northern arm at the lower elevation (R=0.338, p=0.028) (Figure 11) while communities were all similar in the middle elevation (R=0.369, p=0.048) (Figure

12). The difference in the lower elevation were driven by increased tubificid oligochaetes and lower insects in the western and eastern arms as compared to the northern arm.

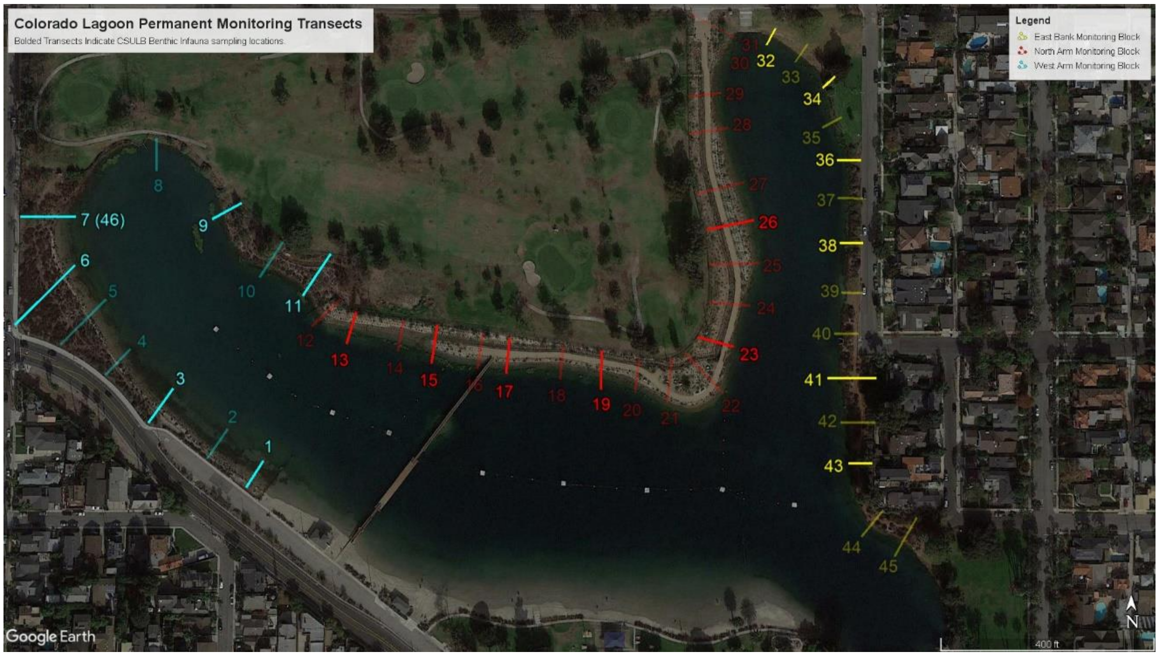

Figure 1. Map of the Colorado Lagoon, showing all transects with the transects sampled for this project in bold. Map credit: N. DaSilva

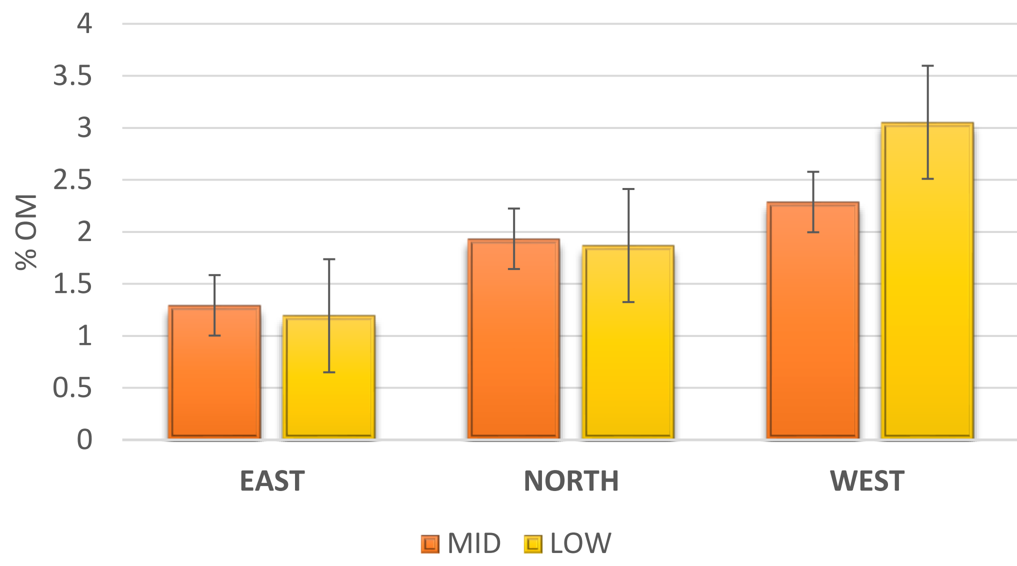

Figure 2. Percent sediment organic matter at each location (eastern, western, and northen arm) for the MID and LOW region.

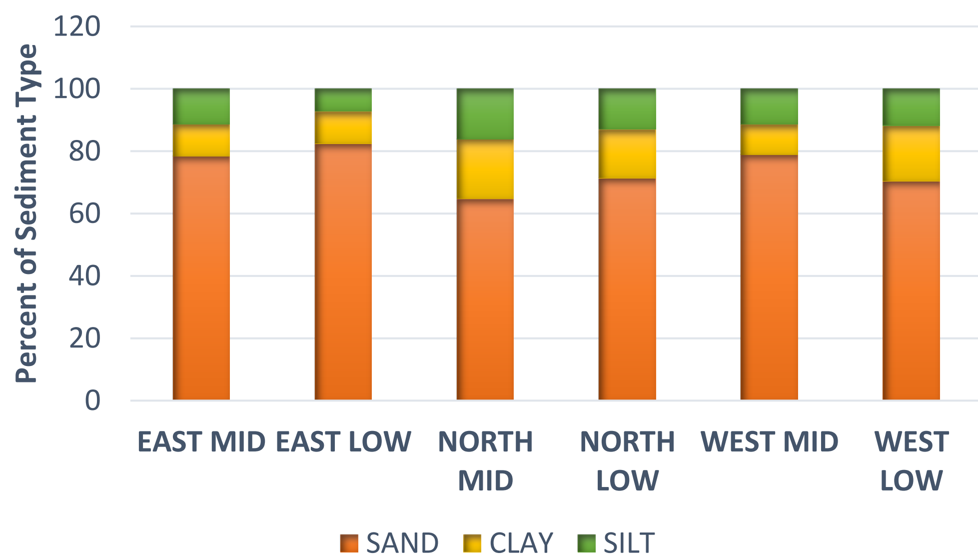

Figure 3. Percent sediment type of sand, clay, and silt at each location (eastern, western, and northen arm) for the MID and LOW region.

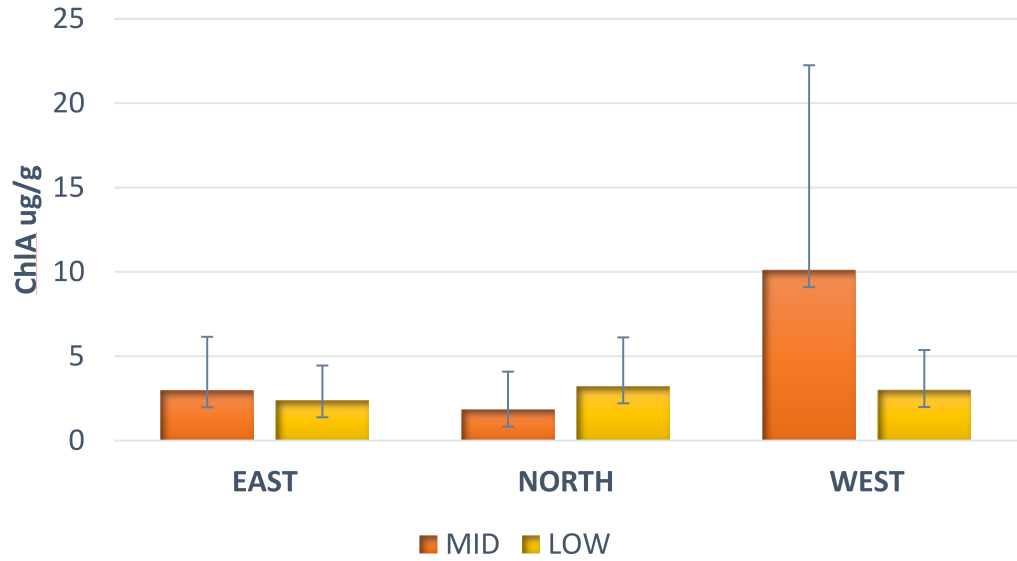

Figure 4. Amount of Chlorophyll A at each location (eastern, western, and northen arm) for the MID and LOW region.

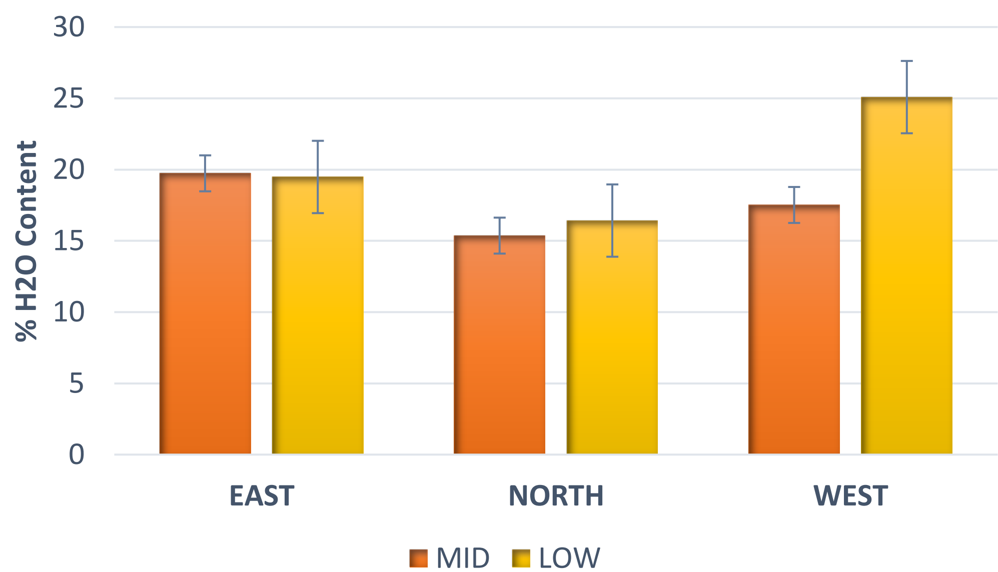

Figure 5. Percent water content at each location (eastern, western, and northen arm) for the MID and LOW region.

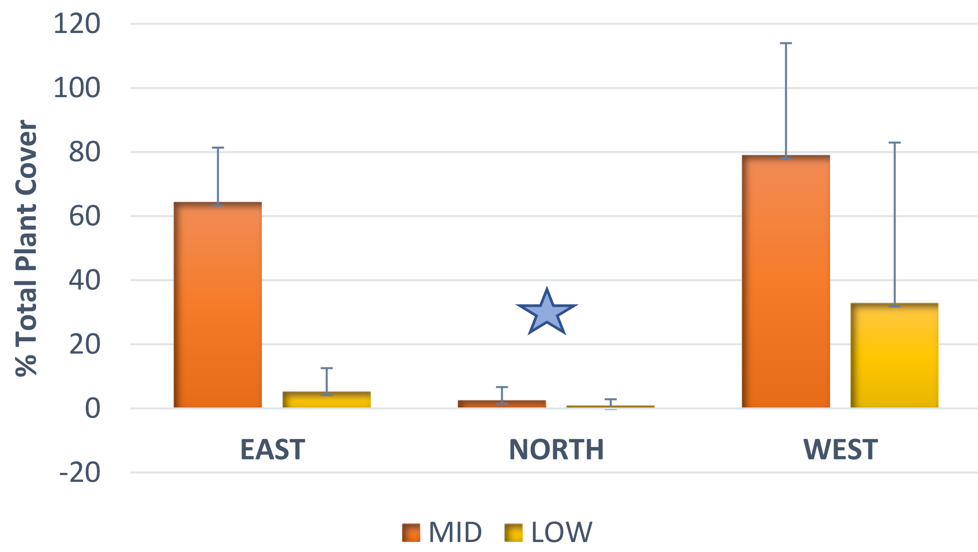

Figure 6. Total plant cover at each location (eastern, western, and northen arm) for the MID and LOW region. Star symbol indicates that there was significant difference in the northern arm.

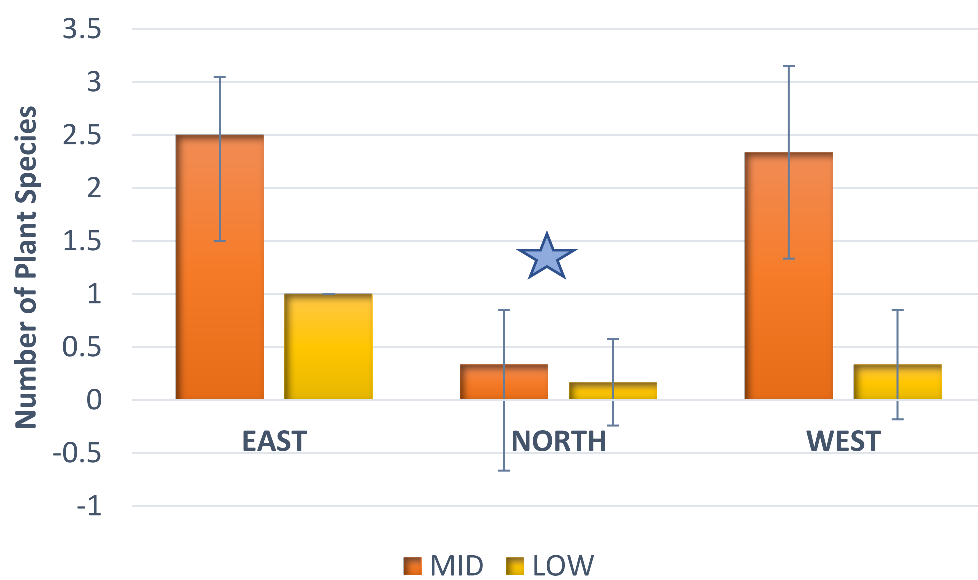

Figure 7. Plant species richness at each location (eastern, western, and northen arm) for the MID and LOW region. Star symbol indicates that there was significant difference in the northern arm.

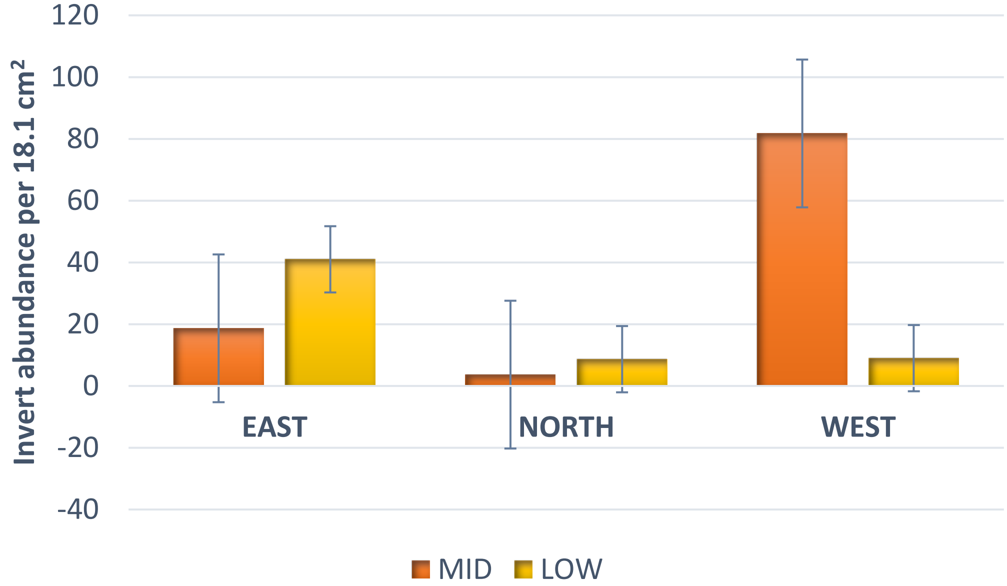

Figure 8. Invertebrate abundances at each location (eastern, western, and northen arm) for the MID and LOW region.

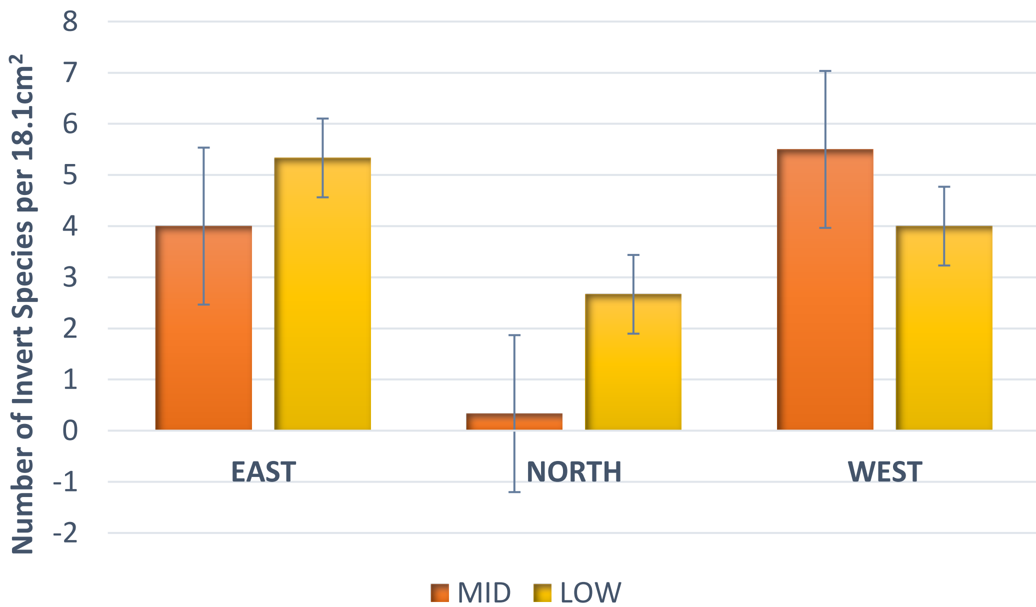

Figure 9. Invertebrate species richness at each location (eastern, western, and northen arm) for the MID and LOW region.

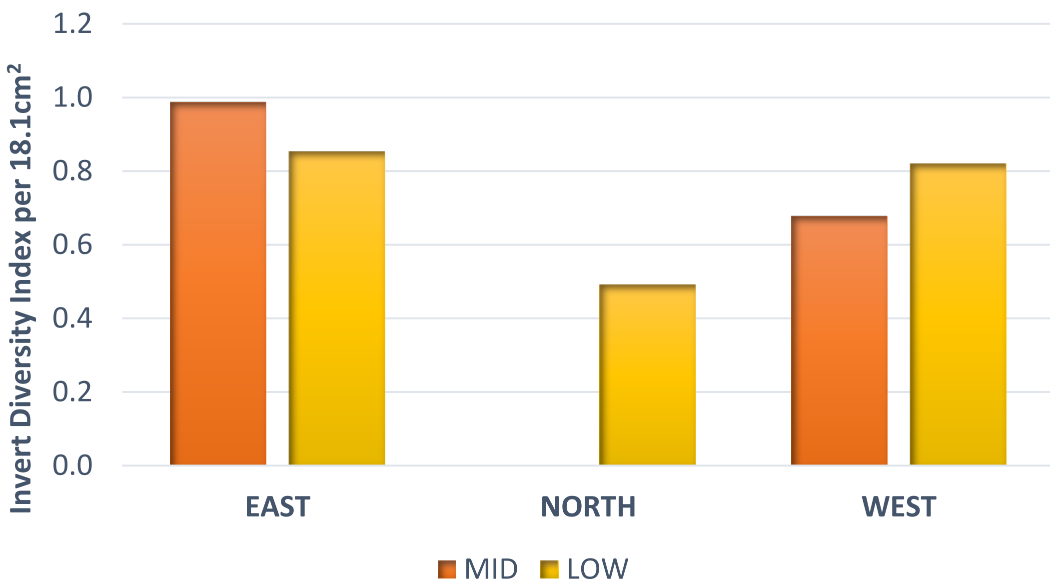

Figure 10. Invertebrate species diversity at each location (eastern, western, and northen arm) for the MID and LOW region.

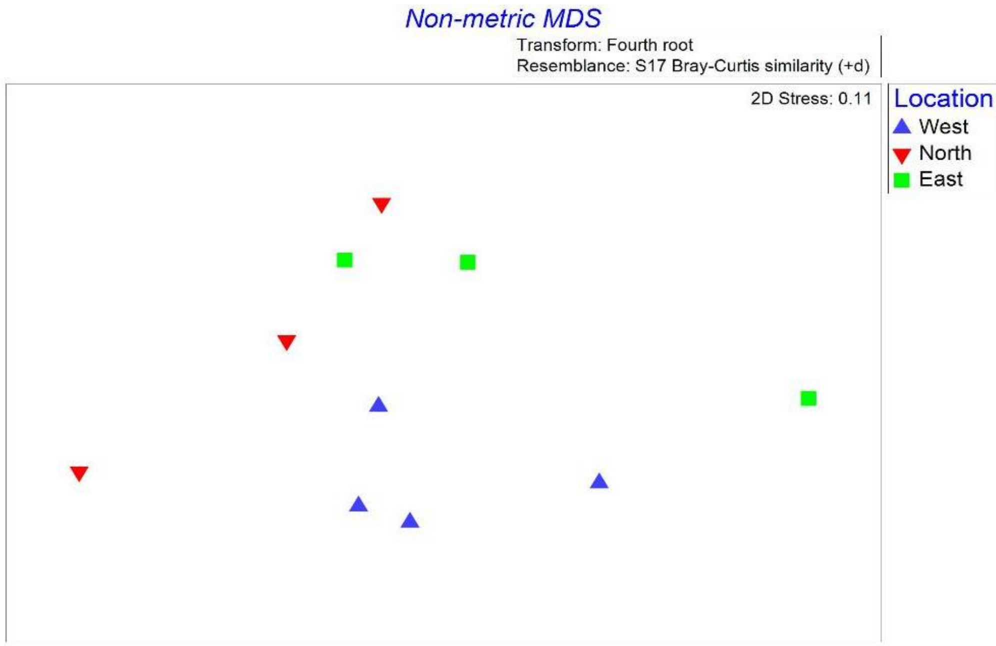

Figure 11. nmMDS of invertebrate community composition at each location (eastern, western, and northen arm) in the LOW region.

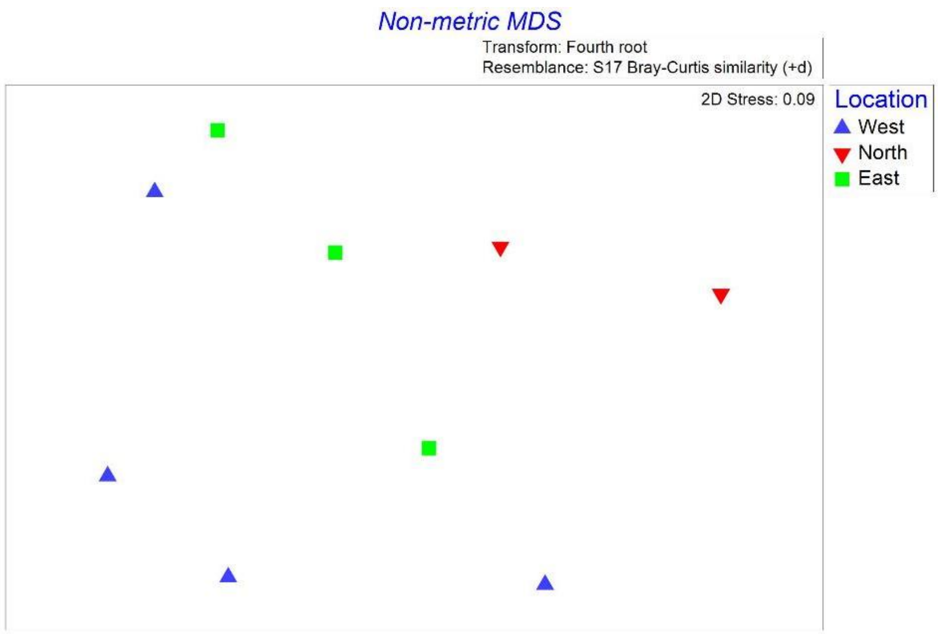

Figure 12. nmMDS of invertebrate community composition at each location (eastern, western, and northen arm) in the MID region.

CHAPTER 4

DISCUSSION

In this paper I have highlighted the importance of plant cover, potentially through active planting, in facilitating the restoration of an urbanized wetland. In my hypotheses I predicted that the eastern arm would resemble a more natural marsh in terms of invertebrate community and sediment characteristics, e.g. presence of tubificid and enchytraeid oligochaetes, higher plant cover and species richness, highest percent organic matter, low Chlorophyll A, and lowest percent sand content. I also predicted that the northern arm would show the opposite; presence of opportunist invertebrates like insect larvae and terrestrial isopods, lowest plant cover and species richness, lowest percent organic matter, high Chlorophyll A, and highest percent sand content. Through my study, I found some variation in these predictions which I will discuss.

In my total plant cover and plant species richness, I had found that the northern arm had significantly less from the eastern and western arm. This was expected as the newly restored area still needs time for the plants to be established and perform its various services. With these significant results it highlights how plants are key in understanding urbanized wetland restoration and the restorative process. The abundance of plant life and diversity of plant species are essential to the restoration process as, mentioned before, they facilitate services like nutrition and habitat for various macro and micro-fauna such as oligochaetes or migrating birds, allow for soil formation and protection, and maintenance of the nitrogen cycle which helps with natural waste management (Anup, 2014). The importance of plant diversity to ecosystems is also highlighted in Allan et al. (2011) study which found that areas with higher species richness have more stable ecosystems compared to less diverse ones, due to the richer communities having better functional turnover, higher productivity, and higher biomass production. This study supports the overall concept that plant diversity is both pivotal in the long-term success of wetland habitats, as well as keep valuable wetland services operating.

In my sediment parameters, I had found no significant differences between the arms within each location, but, generally, there was an unexpectedly high percentage of sand across the arms. These results were expected for the northern arm – as the area was dredged earlier in the year – but in the eastern and western arms I had anticipated a much higher presence of clay and silt within the soil. This high percentage of sand is not ideal due to wetlands typically possessing this characteristically organic-rich and moist soil which is ideal for the wetland-specific plants, as it better provides the necessary nutrients for those plants, therefore higher percentages of sand may possibly be affecting other parameters, like plant cover and richness. Some potential reasons for this trend across the lagoon could be the dredging that occurred a few months prior or the sand that is brought to the site for beach maintenance. The process of dredging can heavily impact an area, and, with the most recent restoration project that dredged the entire northern beach, it could have notably affected the other arms given that all the arms are in relatively close proximity to one another.

In regard to Chlorophyll a and water content, I found no significant differences, and this could have occurred for a few reasons. Chlorophyll a results may not be the most consistent as they can vary depending if the small core that was retrieved happened to have plant matter. To potentially have more significant results, it is recommended to collect additional samples of Chlorophyll a cores as my amount may have been too little for how variable the test can be. As well, percent water content may not have been significant among the arms due to the areas experiencing similar inundation as they are at a similar elevation.

From my invertebrate analyses, I found that species abundance was generally similar across each of the arms, while species richness and diversity was almost significantly lower in the northern arm. So just as predicted, the northern arm ultimately had a less developed invertebrate community than the other two arms. One potential reason why there was a decrease in richness and diversity goes back to there being a high percentage of sand in the soil – as it does not set the foundational setting for these plants to grow as well, therefore in turn these deposit-feeders will not have access to a well-develop plant detritus and live root system as a source of food and protection.

Finally, invertebrate community composition showed different patterns between the mid and low zones. In the lower zonation, I found that the western arm was not like the northern or eastern arm, but the northern and eastern arm were fairly similar to one another. While in the middle zonation, I found that the western arm was more similar to the eastern arm than to the northern arm, and the eastern arm was also similar to the northern arm. Therefore, in the middle zonation, the eastern arm's community structure was like both the western and northern arm, whereas the western and northern arm's community structure was never similar to one another. One reason the arms may have community structures like this, may be because the eastern and northern arms are closer to one another than to the western arm. Incorporate factors like the dredging that occurred on the northern bank, events that occurred within the northern arm may have directly affected certain community parameters in the eastern arm which cause it to have unexpected results away from a natural marsh. As such, distance from the northern arm may explain why the western arm seemed to do slightly better than the eastern arm in some tests as the western arm is further from the other two arms. Despite some differences that the western and eastern arms may have, they are often found similar to one another – they are the oldest banks at the lagoon meaning that it is expected they mainly have similar community parameters.

CHAPTER 5

CONCLUSIONS

Maintaining plant species diversity and abundance is essential to the long term, restorative health of a wetland ecosystem. Wetland ecosystems are important due to their versatile services and functions. So, plant biodiversity not only makes the ecosystem more stable, but it facilitates the success of many of these services; like soil formation, high biomass production, and natural waste management. My data suggests that active planting might be a way to ensure that restoration is a success and may speed up the recovery of such wetland systems. If plants are brought back to higher percent cover faster, this can more quickly improve organic matter content and help speed recovery of invertebrates (as seen in Blair et al. 2013).

Further Research

Further research should be conducted to analyze how distances between the arms may affect the restorative progress of the respective arm. We have seen that the dredging played a probable role in disturbing the percent sand across all arms, so testing how significant of an affect these types of events have on the eastern arm compared to the western arm can help improve understanding of the recovery process in highly urbanized regions and possibly develop methods that foster a more productive restoration plan for the eastern and western arm. It would be equally beneficial to continue monitoring the plants as they become more established within the lagoon and consider what changes that development would have on the parameters tested in this study.

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