GEOGRAPHIC DISTRIBUTION OF *OKENIA HYPOGAEA* AND SOIL ANALYSIS ALONG THE COAST OF JOHN D. MACARTHUR BEACH STATE PARK

by

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Jon Moore, and has been approved by the members of her supervisory committee. It was submitted to the faculty of The Honors College and was accepted in partial fulfillment of the requirements for the degree of Bachelor of Science in Physical and Biological Sciences.

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ABSTRACT

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Title: Geographic Distribution and Comparison of *Okenia hypogaea* along the Coast of John D. MacArthur Beach State Park

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Okenia hypogaea is a rare vine-like dune plant found only in Mexico and five counties on Florida's southeast coast, from St. Lucie to Miami-Dade County. At John D. MacArthur Beach State Park, GPS coordinates of all *Okenia hypogaea* within the park were collected to create a map. I repeated this process following substantial beach erosion, caused by Hurricane Dorian, to compare growth patterns and geographic distribution. This data can be utilized by park officials when managing this species.

Soil analysis along the same 1.3-mile stretch of beach was done to evaluate environmental parameters impacting *Okenia*'s distribution and growth. Ten samples collected in the North region and ten in the South region of the beach were compared to determine any differences in their chemical composition that may affect *Okenia hypogaea* distribution. The tests performed on the soil measured pH, salinity, concentrations of various metals, petroleum products, and polycyclic aromatic hydrocarbons.

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Introduction

Okenia hypogaea is a flowering plant found along the coast of southern Mexico and five counties on South Florida's east coast from St. Lucie County to Miami-Dade County. Also known as the Burrowing Four O'clock or Beach Peanut, it is a vine-like dune plant that is considered an indicator species of dune health and is listed as endangered in the state of Florida. It is a pioneer species as it can burrow its reproductive organ underneath the sand to protect from predators and desiccation. The bright purple flowers bloom in the spring. There have been documented sightings of the plant in Mexico along both East Atlantic and West Pacific coasts, but it has not been extensively mapped or studied.

After a three-month long internship at John D. MacArthur Beach State Park (MBSP) in 2018. I recorded the location of all known individuals of *Okenia hypogaea* along its 1.3 mile stretch of beach and plotted the coordinates on a map. In order to highlight specific trends, I created two different maps to represent the data. The first map depicts each individual recorded coordinate of *Okenia hypogaea*. From this map you can clearly see the clusters of plants, but not how many plants occupy each zone. In the second map, each dot's area represents the number of individual plants per zone. Twenty soil samples were also collected along the stretch of beach and analyzed for diesel, polyaromatic hydrocarbons, various metals, pH, and salinity in order to determine any correlations with the distribution of *Okenia hypogaea* and to compare the North and South zones for discrepancies. Any deviation from the norm in terms of these parameters can negatively affect plant growth in that area.

History and Background

MBSP is located on Singer Island, Florida in North Palm Beach. The park was first opened to the public in 1989. It is named for John D. MacArthur, whose foundation donated the land on which the park is located. The park contains several unique Florida communities within its 437 square acres, including tropical maritime hammock, coastal dunes, and an estuary (MBSP 2005). Within the park boundaries are Munyon Island and a 7,000 feet-long stretch of beach on the Atlantic coast, as seen in *Figure 1*. The beach is a nesting ground for sea turtles, including the loggerhead, green, and leatherback sea turtles. A boardwalk over the estuary grants visitors access to most areas of the park, but the dunes along the beach are restricted from foot traffic to protect vulnerable species including *Okenia hypogaea*.

MBSP is managed by the Florida Department of Environmental Protection under the Division of Recreation and Parks. The Office of Park Planning requires for oversees the coordination of the development and review of state park unit management plans, which are reviewed every 10 years. The last unit management plan for MBSP was reviewed in 2005. The plan provides “detailed inventory and assessment of the natural and cultural resources of the park” including restoration of natural conditions (MBSP 2005). The plan designates the *Okenia hypogaea* a G3, S2 rank under Florida Natural Areas Inventory (FNAI), which identifies a global rank “based on an element's worldwide status,” and a state rank “based on the status of the element in Florida” (MBSP 2011, A-5 1). The G3 rank indicates that it is “either very rare and local throughout its range (21-100 occurrences or less than 10,000 individuals) or found locally in a restricted range or vulnerable to extinction of other factors,” while a S2 rank indicates the plant is “imperiled in Florida because of rarity (6 to 20 occurrences or less than 3000 individuals) or because of vulnerability to extinction due to some natural or man-made factor" (MBSP 2011, A-5 1). According to a ranking system developed by the Florida Endangered Plant Advisory Council, which quantitatively determines the level of endangerment of a plant species, *Okenia hypogaea* is ranked at a 6.0, where a score of 1.5-8.5 is considered endangered and a score of 9.0-12.0 is considered threatened (Ward 2003). This score is determined by factoring in the number of confirmed populations, the number of estimated individuals, the range of the species, the level of protection of its populations, the degree of threat the species is currently facing, and any special considerations such as reproductive potential and unusual circumstances of the habitat (Ward 2003). The *Okenia hypogaea* is therefore classified as endangered and is legally protected in the state of Florida but has not reached national protection status.

Okenia hypogaea is a small creeping annual herbaceous wildflower found along beach dunes and open disturbed spaces along the southeast Florida and southern Mexico coast. While it is confined to these regions, "there is no obvious reason for [its] absence elsewhere in the area" (Moreno-Casasola 1986). It is a member of the Four-O'clock Family, the Nyctaginaceae, within the Caryophyllales order (Wunderlin et al., 2020). It can grow up to 2-6 inches in height and prefers moist, well-drained sandy soils, without humus and requires full sun. The plant has low nutrition requirements, growing in nutrient-poor soils. While it can tolerate high concentrations of salt in the soil and direct salt wind and spray, it has low tolerance for long-term flooding by salt or brackish water. It has a high drought tolerance and does not require any supplemental water once established.

The leaves of the plant have a sinuate leaf margin, as seen in *Figure 2,* meaning they are strongly waved around the margins. The leaves have a red border around the waved leaves and stems. The flowers are dimorphic: a bright purple infertile flower with up to 18 stamens, and a less showy fertile one which is small, closed, and self-fertilizing flowers, depicted in *Figure 3*. The peduncles curve downward, possibly entering the sand, where the fruit develops at the peduncle's tip. The plant contains a taproot which can connect up to five individuals to form a colony. The flowering season is spring to fall, peaking in the summer. The fruit is brown and peanut-like, and is geocarpic, maturing in the fall (Wunderlin et al., 2020). The plant is listed as endangered in the State of Florida, possibly because of human activity, and is a protected species. The regions in which the *Okenia hypogaea* has been identified are highlighted in *Figure 4,* a map that I created.

Most previous studies of this plant concern the properties of the starch obtained from its fruit. This is one of the first extensive studies of the plant's geographical distribution, as it is a little-studied species.

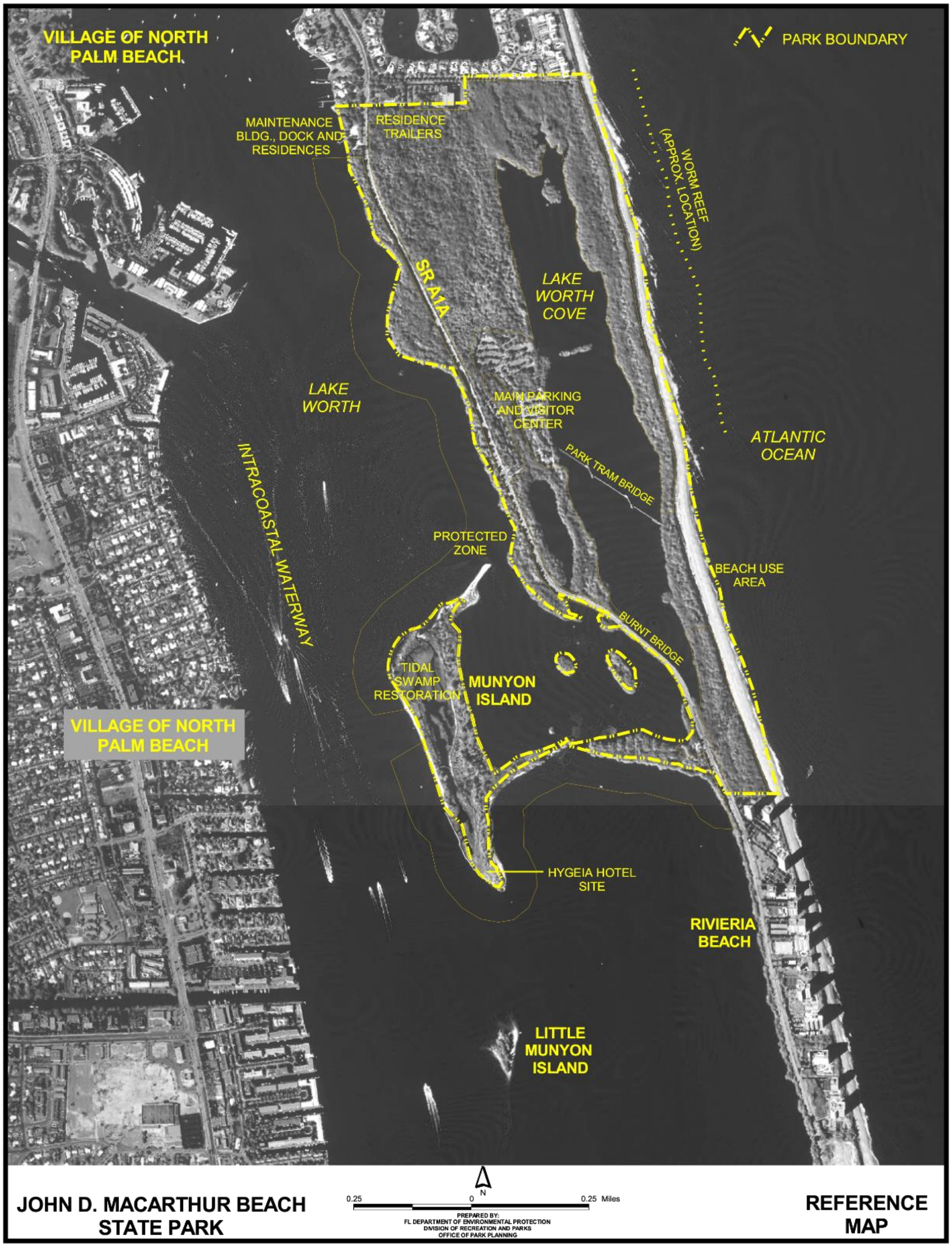

Figure 1: John D. MacArthur Beach State Park Reference Map (from MBSP 2005)

Figure 2: Sinuate Leaves of Okenia hypogaea

Figure 3: Purple Flower of Okenia hypogaea

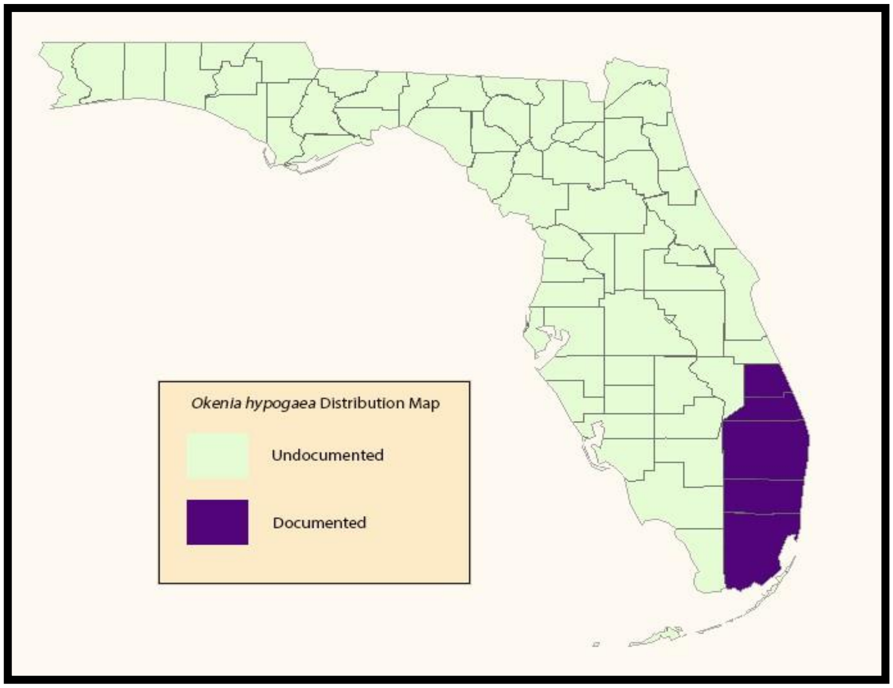

Figure 4: Okenia hypogaea Distribution in South Florida

Part I: Geographic Distribution and Mapping

Description

To better understand the ecology of *Okenia hypogaea,* MBSP started a project to document all individuals present within the park as of November 2018. As an intern at the park, I was assigned as a team member on the project. Over the course of a month, we documented the geographic location of each individual in each zone and made general observations about the size, number of tap roots per colony, and number of flowers found on each individual. After the data was collected, I expanded the project into my thesis by mapping the data using ArcGIS. For the first map, I plotted the latitude and longitude of 355 documented *Okenia hypogaea.* For the second map, I highlighted the number of plants per zone by creating a dot that is scaled in size based on the number of plants in each zone. The area of the dot corresponds to the number of plants in that zone.

In November 2019, one year after the first set of data was collected, I independently revisited the park and replicated the research from the previous year but collecting new data. I surveyed the park for all visible *Okenia hypogaea,* recorded the geographic location of each plant, and made general observations. I then recreated the maps from the previous study using the second-year survey which included 284 individuals. By doing so, I was able to analyze the relation between the first- and second-year maps as well as specific trends within the maps, such as the number of plants in the North zones versus in the South zones within the park. Since *Okenia hypogaea* is an indicator species, the reproductive fitness of the individuals might be indicative of overall dune health.

Materials and Methods

Materials

- Garmin Montana 650 Navigation Device
- Microsoft Office Excel 2016
- ArcGIS and ArcMap (Version 10.3.1)
- Adobe Photoshop 2020 (version 21.1)

Methods

Map 1: Each Individual Coordinate Plotted Year One

The Conceptual Land Use Plan of MBSP designates 16 evenly spaced zones of the 1.3 mile stretch of beach, meaning there is a zone post approximately every 435 feet. The plants found within the zone posts were documented so that an analysis of plants between various zones could be done. After plotting the coordinates of each *Okenia hypogaea* with the Garmin Montana navigation device, I created an excel document to convert the data from degrees, minutes, and seconds into degrees. I then used ArcMap, a geospatial editing component of ArcGIS, to create my map. I first went to "add data" from ArcGIS online and selected "USA States." I added the National Geographic basemap and zoomed in on southeast Florida. I then added my Excel spreadsheet of the *Okenia hypogaea* coordinates.

Map 2: Dot to Represent Number of Plants as Area Year One

The area of each dot corresponds to the total number of *Okenia hypogaea*, N, in each zone. The units used are pixels at 100% zoom in Adobe Photoshop. Each N was scaled 70 times for visibility reasons. To determine the corresponding diameter in pixels for each dot, I used the equation $A=\pi(d/2)^2$, where A represents area and d represents the diameter. I took the number of plants per zone, multiplied by 70, divided by 3.14, found the square root and multiplied by two. I then set the brush size (brush diameter) to that number to create the dot. The calculations for each zone are represented in *Table 1.*

TABLE 1
Plants per Area Calculations—Year One

Zones:	N (Number of Plants):	Diameter (In Pixels) †:
0-1	28	50
1-2	14	35
2-3	10	30
3-4	4	19
4-5	5	21
5-6	0	0
6-7	1	9
7-8	19	41
8-9	23	45
9-10	39	59
10-11	66	77
11-12	64	76
12-13	30	52
13-14	40	60
14-15	12	33

†*Diameter* $= 2 * (N * 70 / 3.14)^{1/2}$

Map 3: Each Individual Coordinate Plotted Year Two

The process from map 1 was repeated using the data from year two.

Map 4: Dot to Represent Number of Plants as Area Year Two

The process from map 2 was repeated using the data from year two.

TABLE 2
Plants per Area Calculations—Year Two

Zones:	N (Number of Plants):	Diameter (In Pixels) †:
0-1	0	0
1-2	0	0
2-3	0	0
3-4	0	0
4-5	0	0
5-6	0	0
6-7	0	0
7-8	0	0
8-9	0	0
9-10	0	0
10-11	22	44
11-12	152	116
12-13	37	57
13-14	23	45
14-15	50	67

† *Diameter* $= 2 * (N * 70 / 3.14)^{1/2}$

Results

The survey in 2018 found 356 individuals in the beach and dunes at MBSP (*Figure 5*). In the North zones were 62 individuals and in the South were 294 (*Figure 6*).

Figure 5: Each Individual Coordinate of *Okenia hypogaea* Year One

Figure 6: Dot to Represent Number of *Okenia hypogaea* as Area Year One

The survey in 2019 found 284 individuals in the beach and dunes at MBSP (*Figure 7*). In the North zones were 0 individuals and in the South were 284 (*Figure 8*).

Figure 7: Each Individual Coordinate of *Okenia hypogaea* Year Two

Figure 8: Dot to Represent Number of *Okenia hypogaea* as Area Year Two

Discussion

Looking at the maps from 2018, *Figures 5 & 6*, there are several trends that stand out. First, there is a large concentration of *Okenia hypogaea* in the Southern region of the park. Zones 0-7, which makeup the Northern region of the park, account for only 17.5% of the 356 documented individuals. The remaining 82.5% of individuals are tightly clustered in Zones 7-15, which makeup the Southern region. Second, there is a large absence of plants in zones 5-6 and 6-7, with only one individual found in both zones. I speculate that this is due to the fact that many people congregate in this area as it is near the bridge that connects to the parking area and nature center. As *Okenia hypogaea* requires optimal conditions, its growth might be stunted in areas with high levels of foot traffic.

The maps from 2019, *Figures 7 & 8,* show drastic changes from the previous year. Again, there was a large concentration of plants in the South zones; however, there were none to be found in the North altogether. Zones 10-15 made up 100% of the 284 documented *Okenia hypogaea*. Zone 11-12 made up 53.5% of total individuals alone. Although direct causation of this loss of plants is unknown, extreme weather conditions may have been responsible. Of the plants that were recorded in 2019, I observed that they were much smaller than the ones that were recorded in 2018. The lengths and widths of each plant were taken both years and on average, the plants the second year were more than half as small as the plants measured the first year. This is strange considering that the surveys were taken around the same time each year, in the Fall between November and December.

MBSP is within the 21-mile-long Lake Worth Lagoon, which has seen "increased pollution associated with the growth of [the] community" (vi) In addition to increased runoff pollution, the Lake Worth Lagoon has seen destruction of coastal aquatic vegetation such as mangroves and seagrass as well as wetland habitats such as the maritime hammocks and beach dunes. It is estimated that “over 87% of the natural shoreline vegetation (mangroves/marsh) has been disturbed” and replaced with coastal fortifications such as sea walls; as little as “19% of the Lagoon remains lined by mangroves” (Chesnes et al. 2011, 90). Looking at aerial photographs of the Lake Worth Lagoon, as seen in *Figure 9,* there is a “lack of natural shoreline in the lagoon outside of the park” (Chesnes et al. 2011, 91). The shrinking of coastal dunes within the Lake Worth Lagoon due to human activity might explain why the North region of MBSP is narrower than the South region. The problems facing the Lake Worth Lagoon are not constrained only to those areas outside the park, as “contaminants and toxins from urban and agricultural runoff, along with elevated loads of nutrients and suspended and dissolved organic matter,” contributes to the environmental distress of all estuaries within the lagoon. Solutions to these problems are set out in the 2011 Lake Worth Lagoon management plan, but the challenge of improving water quality while “accommodating future growth will have to be balanced with competing social and economic needs of local communities” (vi). The plan indicates that the altered hydrology and “large-scale freshwater releases” from up-current canals pose foreseeable challenges to the health of southeast Florida coastal sites (Lake Worth Lagoon, 2011). Long-term monitoring of these systems and continual surveys provide park officials and environmental protection agencies with valuable data to the ecosystem health along the southeast coast, as “habitats where inventories have not yet been initiated, rare or endangered species may be lost without notice” (Chesnes at al. 2011, 95). The documentation of the changing population of *Okenia hypogaea* can be used by Florida Department of Environmental Protection in the next MBSP management plan, which is long overdue.

In addition to the anthropogenic coastal degradation within the century, another possible reason for the decrease in plant individuals and plant sizes from year one to year two might be due to extreme weather that had hit the area just months prior to the second survey. In late August of 2019, Hurricane Dorian devastated coral reefs in the Bahamas and surrounding areas. Dorian came to a standstill over Grand Bahama Island about 70-80 miles east of MBSP for a few days and then headed north. This meant that high surf conditions were felt along the southeastern coast of Florida for more than a week. The category 5 hurricane caused catastrophic damage along the southeastern United States, with significant erosion of beaches and dunes, and possibly impacted the dune health at MBSP by sweeping away dormant seeds with strong winds. Following the hurricane, preexisting *Okenia* were visibly excavated by surf and the level of the upper beach was much lower than it had previously been, with many of the plants no longer visible. Since the *Okenia hypogaea* blooms in the spring, it is plausible that the hurricane disrupted the growth of the seeds which would explain why the plants were smaller in 2019 than they were at the same time the previous year.

Another possible influence for the decrease in *Okenia hypogaea* could be due to the algae bloom termed the “red tide.” The phenomenon is caused by the dinoflagellate *Karenia brevis* which carry chemical stressors known as brevetoxins (Reynolds et al., 2020). Research from the University of North Florida suggests that algae blooms have become more prevalent due to the “enhanced nutrient availability through increased urbanization and agricultural expansion” and is suspected to be made worse by the increasing threat of climate change and ocean acidification (Reynolds et al., 2020). The blooms threaten coral ecosystems in South Florida by depleting the water of oxygen and introducing toxins into waterways around the Florida coast. This triggers mass die-offs and population decline in coastal fish and plants. The decrease in *Okenia hypogaea* coincide with the most recent red tide event which occurred around November 2019. It is possible, although not proven, that the algae bloom has an effect on the dune plants of Florida's Southeast coast. This would be a point of possible future research at the park.

To learn more about the population decline from the first year to the second year, I expanded my research from a geographic study to an environmental analysis. Investigating the chemical components of the surrounding soil could possibly determine a correlation with the geographical trends.

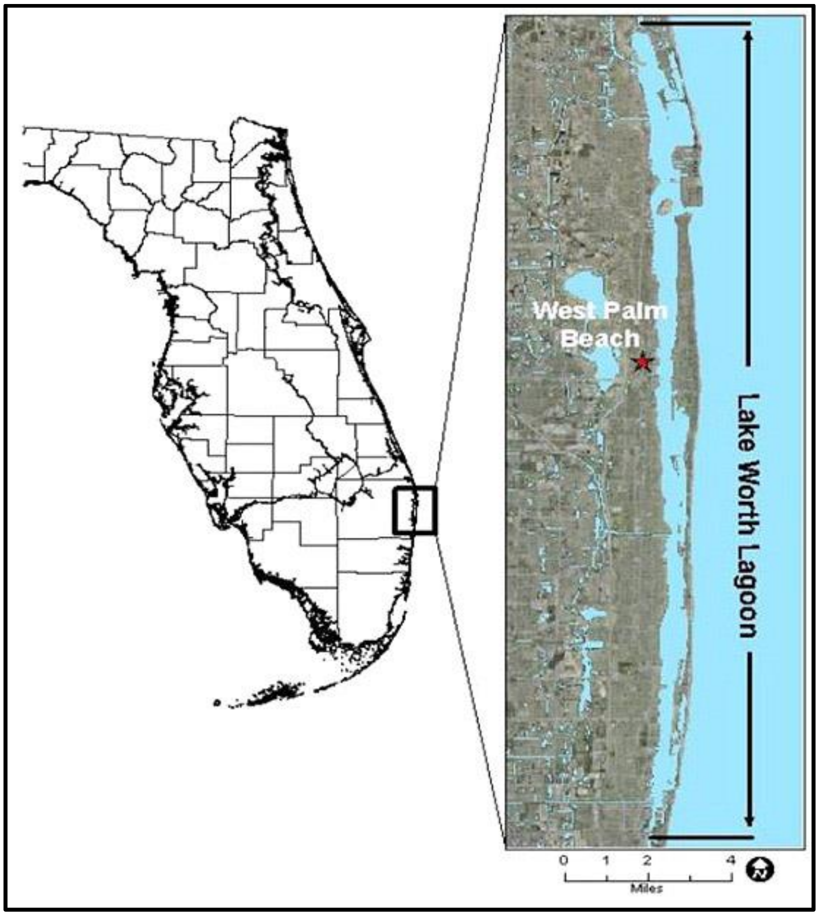

Figure 9: Location of Lake Worth Lagoon
(taken from Lake Worth Lagoon Management Plan, 11).

Part II: Environmental Parameters and Laboratory Analysis

Description

Looking at the differences in the distributions between the maps from 2018 and 2019, I was curious as to why there were significantly fewer individuals in 2019 and why they were completely absent from the Northern zones altogether. Testing the soil surrounding the plants for ecological parameters could suggest a causal connection that reveals the environmental conditions that *Okenia hypogaea* prefer.

I tested the composition of the sands in both the North and South areas using a sample size of twenty: ten per area. All samples taken were evenly spaced throughout the 1.3-mile stretch of the beach at MBSP. Samples 1-10 were taken in the North side of the beach while samples 11-20 were taken in the South side of the beach.

These tests were performed at Jupiter Environmental Laboratories and completed by myself with the assistance of the lab managers, as I am an employee at the facility. The tests include EPA-certified tests such as pH, salinity, metals such as lead and arsenic, Florida Pro, and PAH. The description of each test as well as the methods and procedure are listed below:

pH: This tests for the concentration of hydrogen ions in an aqueous extraction of the soil, which determines the acidity/alkalinity of the soil. This is important because most plants thrive in a certain pH range, and a deviation from that range could result in a reduction in the amount of that species found in an area.

Salinity: This tests for the concentration of sodium chloride in the soil, measured in grams per kilogram of soil. Like pH, most plants thrive within a certain range of salinity, and deviations from their preferred range can alter their distribution within an area.

Metals: This test uses an inductively coupled plasma mass spectrometry (ICP-MS) to ionize the samples and create atomic and polyatomic molecules which are then detected. This machine tests for the concentration of 23 different metals within the soil: beryllium, aluminum, vanadium, chromium, manganese, cobalt, nickel, zinc, arsenic, selenium, silver, cadmium, antimony, barium, mercury, thallium, lead, sodium, magnesium, potassium, calcium, iron, and copper. However, not all of these metals are relevant to what is being studied. Aluminum, calcium, magnesium, and iron are expected to be present in high concentrations due to the nature of the soil and are not likely to have an effect on the distribution of *Okenia hypogaea.*

Florida Pro: This test uses methylene chloride to extract any nonpolar chemicals from the soil. A gas chromatograph is used to measure petroleum concentration in the samples in the C8 – C40 hydrocarbon range (diesel through motor oils). High concentrations of these hydrocarbons found in the soil would indicate human activity affecting the soil and would have a high likelihood of negatively affecting *Okenia hypogaea* concentration due to petroleum being toxic to most plants.

PAH: This tests for polycyclic aromatic hydrocarbons, such as anthracene, phenanthrene, and phenalene. These are found in high concentrations in coal and tar and are also indicative of human activity affecting the soil, such as an oil spill. High concentrations of these chemicals would also be likely to negatively affect soil health and could reduce the concentration of Okenia h*ypogaea* found in an area.

Materials and Methods

<u>pH:</u>

Materials:

- 20 digestion tubes
- 400 ml of deionized water
- OAKTON pH Apparatus

Methods:

1. Measure 20 grams of each sample into their own digestion tube
2. Add 20 milliliters of DI water into each tube
3. Shake tubes for five minutes
4. Wait one hour until the sand has settled
5. Calibrate OAKTON pH probe with known pH samples of 4, 7, and 10.
6. Rinse probe in DI water, insert probe into the sample and wait for test to read "ready"
7. Record pH and repeat step 6 for all twenty samples

<u>Salinity:</u>

Materials:

- 20 digestion tubes
- 400 ml of deionized water
- Hach HQ40D Portable Multi Meter

Methods:

1. Repeat steps 1-4 from pH procedure
2. Calibrate Hach meter with a known sample of salt water
3. Rinse probe in DI water, insert probe into the sample and wait for test to read "finished"
4. Record salinity and repeat step 4 for all twenty samples

<u>Metals:</u>

Materials:

- 20 digestion tubes
- 280 milliliters of concentrated Nitric acid
- 200 milliliters of diluted Nitric acid (250 ml Nitric acid in 2500 ml DI water)
- 60 milliliters of Hydrochloric acid
- 20 watch glasses
- DigiPREP MS instrument
- Agilent inductively coupled plasma mass spectrometry (ICP-MS) system

Methods:

1. Measure 1.9-2.1 grams of sample into Digi tube, repeat for all samples
2. Add 4 ml concentrated Nitric acid into each sample to dissolve metals into solution
3. Let settle for 10 minutes so that samples do not spill over
4. Add 10 ml concentrated Nitric acid, 10 ml diluted Nitric acid, and 3 ml HCl into each sample.
5. Put watch glasses on each sample to collect condensation
6. Put samples into DigiPrep block and heat samples at 95°C for two hours

7. Take samples out of Digiprep block and fill samples to the 50 ml line with diluted Nitric acid
8. Let samples cool overnight
9. Insert samples into ICP-MS instrument to analyze samples for metals

Florida Pro:

Materials:

- Diatomaceous earth
- 22 ASE extraction cells
- 1 milliliter Florida Pro Spike
- 22 milliliters of Florida Pro Surrogate
- 22 ASE cylinders
- Accelerated Solvent Extraction (ASE) machine
- Zymark Turbovap Evaporator
- Agilent GC Flame Ionization Detector (FID) system

Methods:

1. Weigh14-15 grams of the sample and add diatomaceous earth to dry sample
2. Transfer samples into cells
3. Create a method blank with only sand and a matrix spike with one of the random samples to ensure accuracy
4. Add 1 ml of Florida pro surrogate to all samples, MB, and MS.
5. Add 1 ml of Florida pro spike to the MS
6. Put Ottawa sand on top of each sample to prevent leakage and cover with filter
7. Place cells into ASE tray with graduated cylinders aligned directly below cells

8. Let ASE machine run methylene chloride through each sample, approximately six hours
9. Place samples in evaporation machine to reduce volume from 40 ml to 1 ml
10. Place concentrated extract into the GC SVI machine to test for petroleum in samples

PAH:

Materials:

- Diatomaceous earth
- 22 ASE extraction cells
- 2 milliliters PAH Spike
- 22 milliliters of PAH Surrogate
- 22 ASE graduated cylinders
- Accelerated Solvent Extraction (ASE) machine
- Zymark Turbovap Evaporator
- Agilent GC 7890B GC System

Methods:

1. Weigh 14-15 grams of the sample and add diatomaceous earth to dry sample
2. Transfer samples into cells
3. Create a method blank with only sand and a matrix spike with one of the random samples to ensure accuracy
4. Add 1 ml of PAH surrogate to all samples, MB, and MS.
5. Add 1 ml of PAH spike to the MS
6. Put Ottawa sand on top of each sample to prevent leakage and cover with filter
7. Place cells into ASE tray with graduated cylinders aligned directly below cells

8. Let ASE machine run methylene chloride through each sample, approximately six hours.
9. Place samples in evaporation machine to reduce volume from 40 ml to 1 ml
10. Place concentrated extract into the GC SVI machine to test for polycyclic aromatic hydrocarbons in samples

Results

pH and Salinity:

Table 3:
pH and Salinity of All Samples

Sample	pH	Salinity (g/kg)
1	9.25	2.72
2	9.20	2.05
3	9.10	2.93
4	9.28	1.18
5	8.73	0.96
6	9.23	1.52
7	9.06	1.48
8	9.18	1.67
9	9.36	1.08
10	9.19	1.64
11	9.17	2.47
12	9.15	1.00
13	9.39	0.42

14	9.30	2.81
15	9.33	1.73
16	9.38	0.43
17	9.35	0.76
18	9.05	1.48
19	9.45	1.76
20	9.46	1.69

Table 4
Average pH and Salinity of North and South

Avg pH North	Avg pH South	Avg Salinity North	Avg Salinity South
9.158	9.303	1.723g/kg	1.455 g/kg

<u>Metals:</u>

Table 5
Metal Concentrations of All Samples

	Metal Concentration (mg/kg)								
Sample	V	Cr	Mn	As	Pb	Na	Mg	K	Fe
1	3.5	5.5	14	3.9	0.91	2300	2500	94	2000
2	4.2	6.6	17	4.6	1.3	2400	3000	100	2400
3	3.5	5.4	14	3.8	0.86	2500	2800	96	2000
4	3.7	5.7	16	4.0	0.81	2400	3700	82	2400
5	3.7	4.5	15	3.5	0.86	1900	1400	72	2200

6	4.0	6.2	16	4.2	0.93	2100	3000	84	2400
7	3.6	5.7	15	4.1	0.89	2000	2800	82	2100
8	3.9	5.9	15	4.3	0.89	2000	3300	81	2300
9	3.8	5.7	14	4.1	0.84	1800	3000	70	2200
10	3.8	5.8	15	4.2	0.88	2000	3000	84	2200
11	3.7	5.5	15	4.1	0.82	2500	3100	93	2100
12	3.7	5.5	14	4.1	0.80	1800	2800	74	2000
13	3.9	5.7	17	4.3	0.80	2000	3500	71	2300
14	3.4	5.2	14	3.7	1.0	2000	2500	77	1900
15	3.8	5.5	17	4.1	0.87	2400	3200	86	2200
16	3.5	5.2	15	3.9	0.86	1900	3000	59	2000
17	4.4	7.0	21	4.2	2.7	1500	2400	75	2300
18	3.2	3.9	12	3.0	0.73	1800	1200	70	1700
19	4.2	6.2	17	4.4	1.2	2200	2800	88	2400
20	3.8	5.7	16	4.2	1.1	2000	2800	82	2000

TABLE 6
Average Metal Concentrations of North and South

	Metal Concentration (mg/kg)								
Avg. of Zone	V	Cr	Mn	As	Pb	Na	Mg	K	Fe
North	3.77	5.7	15.1	4.07	0.917	2140	2850	84.5	2220
South	3.76	5.54	15.8	4.0	1.088	2010	2730	77.5	2090

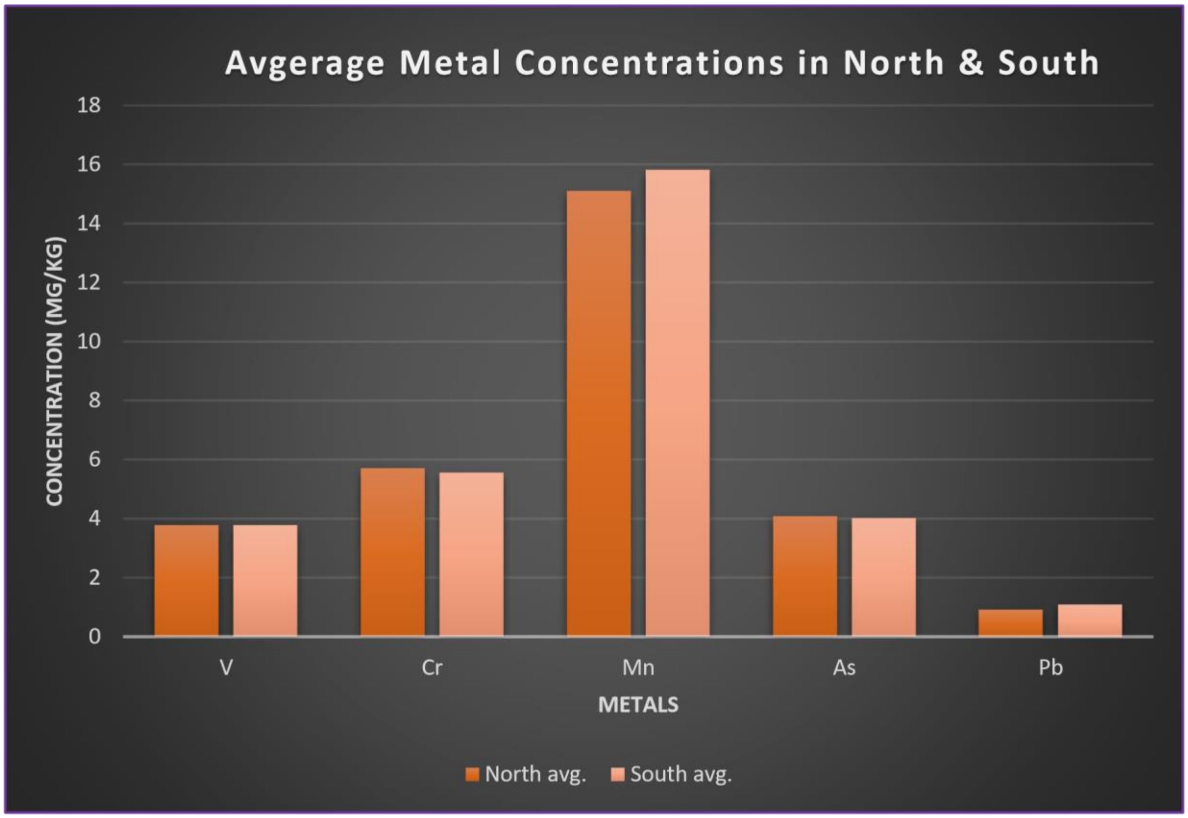

Figure 10: Average Metal Concentration in North and South

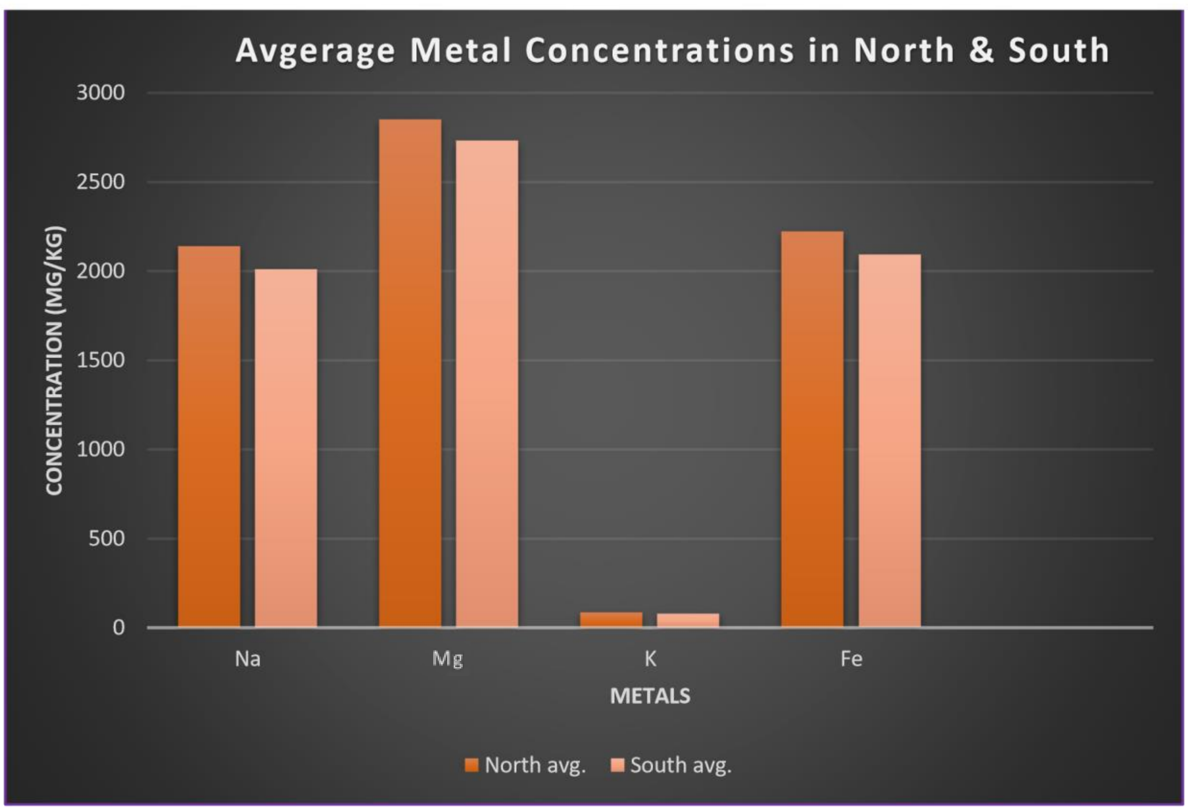

Figure 10 (Cont.): Average Metal Concentration in North and South

Discussion:

In *Table 3*, I recorded the salinity and pH of all 20 samples. I then calculated the averages of these measurements for the North and South zones, recorded in *Table 4.* The average pH for the North was slightly less alkaline than that of the South. The average salinity for the North was 18.4% higher than that of the South. The distinctions between the pH and salinity of the North and South zones are not large, but they could possibly indicate a correlation with the geographic distribution of *Okenia hypogaea*.

Although the ICP-MS system tested for 26 various metals, I chose 9 with the most notable results: Vanadium (V), Chromium (Cr), Manganese (Mn), Arsenic (As), Lead (Pb), Sodium (Na), Magnesium (Mg), Potassium (K), and Iron (Fe). In *Table 5,* I listed the concentrations of each metal in all 20 samples in mg/kg. In *Table 6,* I calculated the average metal concentrations for the Northern region (samples 1-10) and the Southern region (samples 11-20) of the beach. I then created a clustered bar graph, *Figure 10,* in order to highlight the differences in metal concentrations between the North and South regions. I split the figure into two graphs with different scales. After analyzing the graphs, I concluded that there were no outstanding differences in the metal concentrations between the zones. Speculation upon differences between the North and South zones can be found in the conclusion.

Heavy metals contamination of soil results from the "mining and smelting of metals, burning of fossil fuels, use of fertilizers and pesticides in agriculture, production of batteries and other metal products in industries, sewage sludge, and municipal waste disposal" in human occupied territories (Chibuike and Obiora 2014, 1). These anthropogenic activities can "increase the concentration of these elements to amounts that are harmful to both plants and animals" (Chibuike and Obiora 2014, 1). Some metals, such as Iron, Manganese, and Vanadium, are "required in minute quantities by organisms" and are present within seashells, although excessive amounts of these metals can be deleterious to dune ecosystem health (Chibuike and Obiora 2014, 1). Some of the heavy metals found in MBSP, such as Lead and Arsenic, are considered extremely harmful to the flora and fauna of coastal dune environments and should not appear in even minute quantities. When these elements are released into waterways they become "enriched in the sediments by adsorption, complexation, flocculation, and sedimentation," which ultimately results in pollution (Chibuike and Obiora 2014, 1). The bioaccumulation of these metals due to discharged pollution is majorly affected by soil pH as metals have to be in a soluble form to be uptaken by a plant. The availability of these metals also depends upon "soil aeration, microbial activity, and mineral composition." A study by Shandong Jianzhu University reports that "pH is the main factor affecting the adsorption characteristics of heavy metals, which controls the solubility of hydroxides, carbonates, and phosphates of heavy metals and also affects the hydrolysis of heavy metals in sediments and organic matter" (Zhang et al. 2018, 2). Since the soil within MBSP is largely alkaline, the plants are not as an increased risk of soil toxicity due to heavy metals.

As for the PAH and Florida Pro tests, the concentrations of polycyclic aromatic hydrocarbons and petroleum products were not high enough to be detected. This means that the levels of these pollutants were below 0.1 mg/kg and are insignificant. This was the anticipated outcome as I did not expect to find many manufacturing byproducts within the protected state park.

Conclusion

After conducting environmental parameter tests of pH, salinity, and metals, salinity seemed to be the only parameter that could possibly account for the contrast in the number of plants between the North and South. Factors that may influence the changes in population densities from North to South incudes the width of the beach and the steepness of the dunes in each area. The North region of MBSP has a thinner beach, possibly caused by beach erosion, meaning that the tide line is closer to the dunes in the North than it is in the South region. As indicated in my tests, the North region has, on average, a slightly higher salinity than the South region. As *Okenia hypogaea* is a dune plant, it could possibly prefer the South because it has less contact with the salt water. The slight increase in salinity in the North zones could be due to the increased proximity to the tideline and therefore more salt spray settling on the beach, which leaves behind crystalline salt as it evaporates.

The North region of the beach also has a steeper dune which likely developed due to the presence of vegetation that prevents sand from being eroded into the ocean. The accumulation of sand forms a dune ridge within the foredune. According to Patrick Hesp in “Ecological Processes and Plant Adaptations on Coastal Dunes”, such dunes generally contain less “microorganisms and local habitats” (1991). This is due to the high wind exposure, sea spray, soil salinity, nutrient deficiency, and varied sunlight which causes stress levels to increase and species richness to decrease. Since *Okenia hypogaea* requires full sunlight, it is plausible that the low population in the North is due to plants only receiving sunlight in the first half of the day as the sun rises in the East. As the sun progresses to the West, the sunlight is partially blocked by the sharp incline of the dune.

The dune in the Southern region, however, is broad and flat. This gives plants maximum sun exposure throughout the day, resulting in more optimal conditions for *Okenia*.

Another possible factor to look into is the concentration of other dune plants in the North and South zones, which may indicate if the *Okenia hypogaea* has an affinity or an aversion to nearby plants. For instance, the Beach Star, *Remirea maritima*, grows in abundance in the South region of MBSP, which is also where the largest concentration of *Okenia hypogaea* was documented.

The data gathered can point future research towards possible influences and correlations, such as examining the effect each metal has on beach plants and dune health. Another interesting question to study is if the levels of sodium and potassium, significant components of sea salt, correlate with the salinity of each zone.

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