# Feasibility Study of a Full Scale Seaweed Compost System in South Florida

# (FINAL)

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**PROJECT TITLE**: Feasibility Study of a Full Scale Seaweed Compost System


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**PROJECT DURATION:** August 1, 2021 to March 31, 2023


**ABSTRACT:** *Sargassum* spp. has been "invading" the beaches across Florida in recent years during spring and summer months. Massive strandings have left municipalities unable to deal with the problem. Ft. Lauderdale, however, has tackled the problem by implementing a unique and sustainable practice of composting. For the past 13 years, Ft. Lauderdale has implemented this practice, which has been successful in removing the large strandings of *Sargassum* at the beach and have fine-tuned the process controlling smaller deposits to optimize beach ecology and aesthetics. If other municipalities around South Florida were to follow suit with this example, there will be more space in landfills and a maintained tourist appeal. The objective of this proposal is to assess the feasibility of a full scale seaweed compost system. The project will be divided into two phases. The first phase will involve performing an cost analysis on the operation that Ft. Lauderdale has been running, and to examine the logistics behind the operation. Part of this phase will include examining the markets for  substitute products for seaweed compost to determine the potential revenue from the sale of the compost. The second phase will include analyzing samples from the Ft. Lauderdale compost piles to document its quality. Each of the samples collected during phase II will be analyzed for bulk physical-chemical properties of the compost (including salinity), nutrients (including carbon, nitrogen, and phosphorus), and bacteria.  Results will be compared to the U.S Composting Council

(USCC) requirements and to sewage sludge land application guidelines (Class A biosolids). *Sargassum* composting has the potential to preserve landfill space, convert a waste material into a beneficial use, and save municipalities millions while maintaining the high quality of coastal beaches.

**Key Words:** *Sargassum*, seaweed, compost, metals, cost analysis

**METRICS REPORTING**
This page will be omitted from the report when it is published.

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**Metrics:**

1. Research publications from THIS Hinkley Center Project.
   JOURNAL ARTICLES
   - Abdool-Ghany, A.A, Oehlert, A.M., Swart, P.K., Blare, T., Moore, K.M., Solo-Gabriele, H. M. Assessing Quality and Beneficial Uses of *Sargassum* Compost. Manuscript in Preparation.
   - Abdool-Ghany A.A., Blare, T., Solo-Gabriele, H. M. Assessment of *Sargassum* spp. Management Strategies in Southeast Florida. Manuscript in Preparation.

   PUBLISHED OUTREACH DOCUMENTS
   - Blare, T., Abdool-Ghany, A. A., Solo-Gabriele, H. M. 2022. Cost Estimates for Producing *Sargassum* spp. Compost- English. *University of Florida Institute of Food and Agricultural Sciences EDIS.* (In press)
   - Blare, T., Abdool-Ghany, A. A., Solo-Gabriele, H. M., Gonzalez, E. 2022. Costos Estimados de la Producción de Sargazo Compostaje . *University of Florida Institute of Food and Agricultural Sciences EDIS.* (Spanish version, in press)

   ABSTRACTS
   - 2022 Goldschmidt Conference Abstract, International Conference on Geochemistry and Related Subjects, organized by the Geochemical Society and the European Association of Geochemistry
     - **Title:** Is composting a feasible disposal option for beach-stranded Sargassum in South Florida?
     - **Description of Material:**
   - Over the last decade there has been increased proliferation of *Sargassum* in the north Atlantic Ocean, with massive strandings occurring on near annual frequency in the Caribbean, western Africa, and United States since 2011. Such events have

environmental, health, and economic impacts, because *Sargassum* is known to have a high capacity to absorb metals from the environment [1]. A common disposal method is mechanical collection of the stranded *Sargassum* and subsequent landfill disposal. Thus, leachates of degrading *Sargassum* can contribute to contamination in soils and groundwater near landfills. Compost can be a potential solution and can present a sustainable management method if concentrations of potentially toxic metals are below EPA guidelines. The objective of this project is to determine whether composting is a feasible management solution for *Sargassum* strandings. We assessed compositional characteristics of the compost [nutrient ratios (C:N, P), elemental concentrations, abundance of indicator bacteria] in both small-scale and large-scale settings. The first phase (small-scale) of study involved experiments using tumbler composters, which independently evaluated the impacts of washing the *Sargassum* prior to composting, as well as the impact of mixing with other vegetative wastes (grass, mulch, etc). The second phase (large-scale) involved two 4 $yd^3$ compost piles with different additives (a control pile and vegetative waste) in a municipal setting. In the first phase, the mixture of *Sargassum* and grass clippings produced compost with the best C:N ratios and lowest concentrations of toxic metals. Bacteria levels did exceed EPA regulatory limits in this treatment. Preliminary radish bioassay experiments also suggested best growth in the compost treatment mixed with grass clippings. Unwashed *Sargassum* produced compost with moderate C:N but the highest concentrations of toxic metals. Within the larger scale experiments conducted in the second phase, the *Sargassum* treatment produced the best C:N ratios and lowest bacteria levels compared to the *Sargassum* and vegetive waste treatment.

[1] Rodríguez-Martínez, R. E., et al., (2020). *PeerJ*, *8*, e8667.

- 2021 Florida Shore and Beach Preservation Association (FSBPA) Annual Conference Abstract
    - **Title:** Sargassum Invasion: Composting as a Solution
    - **Description of material**

*Sargassum* spp. is one of the dominant forms of marine macroalgae (seaweed) found on beaches throughout Florida. Excess *Sargassum* is washing up on the shores of Florida beaches and originates from the Sargasso Sea in the Northern Atlantic Ocean near Bermuda. Recently there have been large quantities of *Sargassum* reported in the central Atlantic Ocean and the Caribbean Sea. During the summer of 2018 and 2019, record amounts of *Sargassum* spp. were documented along beach coastlines resulting in local authorities hauling this seaweed to the nearest landfill. Hauling and landfill disposal of seaweed can cost the cities and municipalities hundreds of thousands of dollars per year.

The influx of *Sargassum* onto the shores is important to maintain the ecological balance. The difficulty has been when the amounts of seaweed stranding onshore are excessive. When excessive, the local ecology suffers and the aesthetics of the beach decline. In extreme conditions, the seaweed is so thick on the water surface that turtles are unable to surface for air, thus drowning in embayments where the Sargassum accumulates. When excessive amounts of *Sargassum* are found on the sand, it also contributes to a decline in the aesthetic quality of Florida beaches and ultimately impacts on the tourism industry. When left on the shore to decompose, the *Sargassum* will release unpleasant odors (hydrogen sulfide) into the environment. It also attracts insects, e.g. sand flies, as it decomposes. Bacteria levels in the seaweed also tend to increase. When the decomposing *Sargassum* is washed back to the water it results in the issuance of beach swim advisories due to elevated bacteria levels further impacting the economy of the area by limiting access to safe recreational waters along the coast. Thus, coastal communities are looking for alternative ways to handle the material once removed from the beach.

Alternative methods are needed for handling excessive amounts of Sargassum that are found on Florida's coastlines. In order to combat this problem, local government agencies are exploring how to remove the seaweed and are looking for beneficial uses. Composting offers one potential and beneficial alternative. Instead of leaving the seaweed to decompose on shore, or hauling it off to landfills via trucks, Sargassum can be potentially composted. Compost consists of decomposed organic matter. This natural process of recycling organic matter can be used to produce a rich soil amendment. Compost maintains moisture more effectively and provides a rich environment for plants to grow. Seaweed is rich in nutrients that are absorbed from the sea and from the energy from the sun, making it a potentially rich soil amendment. In addition to its use as a soil amendment, it should be ensured that the composting of seaweed is within the standards of heavy metals and bacteria levels so that the constituents are within satisfactory health-based levels. The objective of this project is to evaluate the suitability of producing compost from seaweed in tumbler composters.

Four experiments were conducted to evaluate the need for pre-washing and suitable mixes. The treatments included: no washing of *Sargassum*, washing *Sargassum* with freshwater, grass clippings mixed with *Sargassum*, and mulch mixed with *Sargassum*. These treatments were sampled biweekly and measured for bulk physical-chemical parameters, nutrients, metals, and bacteria. Once the compost was cured, radish bioassays were setup to evaluate the plant growth in each of the treatments. Results indicate that electrical conductivity (saltiness) is not an issue when composting the seaweed (values are well below the U.S Composting Council standards). Preliminary carbon to nitrogen results show that the compost can be used to grow plants. Results from the radish bioassays indicate that the compost can support growth of plants.

2. Research presentations resulting from THIS Hinkley Center Project. The interim results from this study have been presented during the following meetings:
    - "Sargassum Composting-A Potential Management Solution" Annual Conference organized by Recycle Florida Today. June 27th, 2022. (Speaker presentation by A. Abdool-Ghany and H. Solo-Gabriele).
    - "Sources of Enterococci to a Coastal Beach Experiencing Elevated Background Levels" Webinar organized by SOP Technologies, Miami FL. July 2020. (Speaker presentation by H. Solo-Gabriele and A. Abdool-Ghany). [This webinar was attended by over 70 individuals.]

- "Sources of Enterococci to a Coastal Beach Experiencing Elevated Background Levels" Webinar organized by the City of Hallandale Beach, Hallandale Beach, FL. August 2020. (Speaker presentation by A. Abdool-Ghany).
- "Sargassum Seaweed Management in the State of Florida" Webinar organized by Recycle Florida Today. March 18, 2021. (Speaker presentation by A. Abdool-Ghany and H. Solo-Gabriele).
- "Sargassum Composting- A Solution" Presentation organized by Ana Zangroniz of Florida Sea Grant for Miami Dade County Parks and Recreation. June 24th, 2021. (Speaker presentation by A. Abdool-Ghany and H. Solo-Gabriele).
- "Sargassum Composting" Annual Conference organized by Recycle Florida Today. September 8th, 2021. (Speaker presentation by A. Abdool-Ghany).
- "Sargassum Invasion: Composting as a solution" Annual conference organized by Florida Shore and Beach Preservation Association. September 17th, 2021. (Speaker presentation by A. Abdool-Ghany).

3. List who has referenced or cited your publications from this project. Pending

4. How have the research results from THIS Hinkley Center project been leveraged to secure additional research funding?
   - We submitted a pre-proposal to EREF but it was not awarded.
   - We have also submitted a proposal to Commissioner Raquel Regalado of Miami-Dade County. It was intended to evaluate a composting operation located in Crandon Beach. The objective of the proposal was to evaluate the suitability of producing compost from seaweed on a large scale. The Commissioner's Office has indicated interest.
   - Additional proposals are pending.

5. What new collaborations were initiated based on THIS Hinkley Center project?
   - Through Dr. Blare, we have collaborated with individuals in the agricultural community who are helping to set up interviews with growers that work with *Sargassum* compost.
   - With the help of Dr. Blare, we also met Maria Emerson and Tamer Harpke from Harpke Family Farm. We toured their facility on November 1, 2022.
   - We have met with Lanette Sobel, who is the managing partner and CEO of Fertile Earth Worm Farm. Her company produced compost from food waste and mulch. She was interested in composting of *Sargassum* and using vermicomposting. We toured her facility on November 14, 2022 to see her operation.
   - We also met Peter Fedele from Lion Fruit Farms through Lanette Sobel. He was interested in vermicomposting *Sargassum* as well. We toured his facility on November 14, 2022 to see his operation and existing vermicomposting setup.
   - Recycle Florida Today and the Organic Compost Council have been supporters of our research by promoting our work through meetings they organize.
   - We have met with the CEO/founder of Sustainscape Inc, Dennis de Zeeuw. His company produces fertilizer from *Sargassum*. He has two products that he uses throughout his jobs in Broward County. Dr. Blare and Afeefa met with him on September 20, 2021.

- The CEO/founder of Algas Organics, Johanan Dujon, reached out to us to hear more about our research. We learned more about the operation he is running and how he deals with *Sargassum*. We met with him on September 22, 2021.
- There were a total 6 individuals representing government agencies, four commercial growers, and one landscaping business interviewed as part of this project.

6. How have the results from THIS Hinkley Center funded project been used by the FDEP or other stakeholders?
   - Members of the FDEP have participated in our TAG meetings and in meetings organized by our collaborators. They include Karen Moore, Lauren O'Connor, and Chris Perry. The FDEP has provided us with guidance in the process for obtaining permits for on-beach composting projects. They have also provided us with guidance in terms of applicable regulations. Currently they are working on changing Chapter 62-709, F.A.C. FDEP is adding *Sargassum* as its own category instead of being classified as yard waste. The regulations for yard trash do not include arsenic and as a result seaweed compost would pass FDEP regulatory thresholds. The FDEP is interested in our work because it will help guide the agency in terms of classifying *Sargassum* compost. They appear to want to encourage recycling of *Sargassum* and have been keeping up with our work on this project.

**ACKNOWLEDGEMENTS**


- This project was funded by the Hinkley Center for Solid and Hazardous Waste Management.
- We thank the City of Fort Lauderdale for their support in this project and for allowing us to conduct part of this study onsite.
- We thank the beach managers, organic growers, and business owners who provided feedback concerning composting operations through the interview process set up as part of this study.
- We are grateful to all of the Technical Awareness Group (TAG) members listed in the following table, plus the individuals who took part in the TAG meetings who are listed in the table that follows for participating in meetings and for their input and feedback.

## RESEARCH TEAM MEMBERS

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| Afeefa Abdool-Ghany | Graduate Ph.D. Student<br>University of Miami, Dept. of Chemical, Environmental, and Materials Engineering, Coral Gables, FL  33146 |

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**TECHNICAL AWARENESS GROUP (TAG) MEMBERS.** Note: Participation in the TAG group does not imply an endorsement of the research. The TAG group are individuals who are interested in the research and are capable and willing to provide input. This input is considered by the research team as the research project progresses.

| Name | Affiliation |
|---|---|
| Kimberly Moore | Professor in Environmental Horticulture, Distinguished Teaching Scholar<br>University of Florida, IFAS\|Fort Lauderdale Research and Education Center |
| Ligia Collado-Vides | Senior Lecturer; Associate Chair<br>Department of Biological Sciences, Florida International University |
| Dan Meeroff | Professor and Associate Chair<br>Department of Civil, Environmental & Geomatics Engineering, Florida Atlantic University |
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| Randall Penn | UF IFAS Extension Agent - Sarasota County |
| Armando Ubeda | UF/IFAS Extension Sarasota County |
| Michelle Mularz | Extension Services-Environmental Horticulture Agent |
| Vincent Encomio | Sea Grant- Martin and St. Lucie Counties Extension Agent |
| Ashley Smyth | Assistant Professor, Biogeochemistry<br>Tropical Research and Education Center |
| Emilio Lopez | CEO of SOP Technologies |
| Alejandro Quintás | NEAT Sand |
| Chip Jones | President of Beach Raker |
| David Hill | Co-Chair Organics Recycling Committee<br>Recycle Florida Today |
| Nandra Weeks | GeoSyntec Consultants |
| Alyssa Jones-Wood | Green Initiatives Coordinator for the City of Hallandale Beach |
| Cathie Schanz | Director of Park, Recreation, and Open Spaces |
| Mary Beth Morrison | Director of Environmental Programs, Solid Waste Authority of Palm Beach County |
| Enrique Sanchez | Deputy Director, Parks and Recreation of the City of Fort Lauderdale |
| Mark Almy | Park Operations Superintendent<br>Parks and Rec. Admin. |
| Roland Samimy | Chief Resilience and Sustainability Officer |
| Tom Morgan | Chief of Operations, Miami Dade Parks and Rec |

**TECHNICAL AWARENESS GROUP (TAG) MEMBERS (Cont'd)**

| Name | Affiliation |
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| Paul Vitro | Division Chief at Miami-Dade County Parks, Recreation and Open Spaces Department |
| Mark Richard | Senior Region Manager, Miami Dade County Parks and Rec |
| Heather Tedlow | Interpretive Nature Coordinator, Miami Dade Parks and Rec |
| Samir Elmir | Director of Environmental Health & Engineering Service<br>Florida Department of Health in Miami-Dade County |
| Karen Moore | Environmental Administrator-FDEP Division of Waste Management |
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| Chris Perry | FDEP Division of Waste Management |

| **TAG MEETING PARTICIPANTS.** Note: Participation in the TAG meetings does not imply an endorsement of the research. | |
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| **Name** | **Affiliation** |
| **MEETING 1** (Online) | |
| Afeefa Abdool-Ghany | University of Miami |
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| Ashley Smyth | University of Florida, Tropical Research and Education Center in Homestead |
| Chris Snow | Consolidated Resource Recovery, Inc. |
| Christopher Perry | Florida Department of Environmental Protection |
| Danielle Jimenez | Division of Environmental Resource Management (DERM) |
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| Helena Solo-Gabriele | University of Miami |
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| Ligia Collado-Vides | Florida International University |
| Mark Almay | City of Fort Lauderdale |
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| Nandra Weeks | Geosyntec Consultants |
| Patti Emad | Division of Environmental Resource Management (DERM) |
| Peter Swart | University of Miami-RSMAS |
| Roland Samimy | The Village of Key Biscayne |
| Samir Elmir | Florida Department of Health in Miami-Dade County |
| Shelly Krueger | University of Florida, Florida Sea Grant Agent for Monroe County |
| Tom Morgan | Miami-Dade County Parks |
| Trent Blare | University of Florida-IFAS-Homestead |
| Vincent Encomio | Florida Sea Grant Agent for Martin and St. Lucie County |

| **TAG MEETING PARTICIPANTS.** Note: Participation in the TAG meetings does not imply an endorsement of the research. | |
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| Abby Crombie | Georgia Institute of Technology |
| Afeefa Abdool-Ghany | University of Miami |
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| Amanda Oehlert | University of Miami-RSMAS |
| Ashley Smyth | University of Florida, Tropical Research and Education Center in Homestead |
| Danielle Jimenez | Division of Environmental Resource Management (DERM) |
| Daniel Meeroff | Florida Atlantic University |
| Emilio Lopez | SOP Technologies |
| Evan Blanchard | Brizaga |
| Helena Solo-Gabriele | University of Miami |
| Jeffery Davis | Georgia Institute of Technology |
| John Schert | Hinkley Center for Solid and Hazardous Waste Management |
| Kimberly Moore | University of Florida, IFAS |
| Lauren O'Connor | Florida Department of Environmental Protection |
| Ligia Collado-Vides | Florida International University |
| Mark Almay | City of Fort Lauderdale |
| Mark Richards | Miami-Dade County |
| Mary Beth Morrison | Solid Waste Authority of Palm Beach County |
| Michael Antinelli | Brizaga |
| Peter Swart | University of Miami-RSMAS |
| Rebecca Wakefield | Commissioner Regalado's Office in Miami Dade County |
| Samir Elmir | Florida Department of Health in Miami-Dade County |
| Tom Morgan | Miami-Dade County Parks |
| Trent Blare | University of Florida-IFAS-Homestead |

| **TAG MEETING PARTICIPANTS.** Note: Participation in the TAG meetings does not imply an endorsement of the research. | |
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| **Name** | **Affiliation** |
| **MEETING 3** (Online). | |
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| Amanda Oehlert | University of Miami-RSMAS |
| Amede Dimonnay | Broward Engineering and Permitting Division |
| Ana Zangroniz | Florida Sea Grant Extension Agent for Miami Dade-County |
| Chip Jones | Beach Raker |
| Chris Snow | Consolidated Resource Recovery, Inc. |
| Christopher Perry | Florida Department of Environmental Protection |
| Danielle Jimenez | Division of Environmental Resource Management (DERM) |
| Daniel Meeroff | Florida Atlantic University |
| David Hill | Co-Chair Organics Recycling Committee |
| Elizabeth Kelly | Martin County |
| Emilio Lopez | SOP Technologies |
| Evan Blanchard | Brizaga |
| Fanny Navarro | Miami- Dade County Parks, Recreation and Open Spaces; Sea Turtle Conservation Program |
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| Jairo Gonzalez | |
| Karen Moore | Florida Department of Environmental Protection |
| Kimberly Moore | University of Florida, IFAS |
| Lauren O'Connor | Florida Department of Environmental Protection |
| Libbie | Farmer in the British Virgin Islands |
| Mark Richards | Miami-Dade County |
| Mary Beth Morrison | Solid Waste Authority of Palm Beach County |
| Nandra Weeks | Geosyntec Consultants |
| Peter Swart | University of Miami-RSMAS |
| Rachel Harris | Loxahatchee River District |
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| Shelly Krueger | University of Florida, Florida Sea Grant Agent for Monroe County |
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| Susan Noel | Loxahatchee River District |
| Tom Morgan | Miami-Dade County Parks |
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# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| C:N | Carbon to Nitrogen ratio |
| EREF | Environmental Research & Education Foundation |
| F.A.C. | Florida Administrative Code |
| FDEP | Florida Department of Environmental Protection |
| HCSHWM | Hinkley Center for Solid and Hazardous Waste Management |
| PI | Principal Investigator |
| RFP | Request for Proposal |
| RSMAES | Rosenstiel School of Marine, Atmospheric, and Earth Science |
| SCLT | Soil Cleanup Target Levels |
| SIL | Stable Isotope Laboratory |
| SOPF | Source-Separated Organics Processing Facility |
| UM | University of Miami |
| USCC | United States Composting Council |
| US EPA | United States Environmental Protection Agency |

# UNITS OF MEASURE

| | |
|---|---|
| $ | Dollars |
| % | Parts per hundred |
| ºC | Degrees Celsius |
| CFU/100mL | Colony forming units per one hundred milliliters |
| cm | Centimeters |
| kg | Kilograms |
| km | Kilometers |
| L | Liter |
| mg | Milligrams |
| $m^3$ | Cubic meters |
| mm | Millimeters |
| mg/kg | Milligram per kilogram |
| mL | Milliliter |
| mS/cm | Millisiemens per centimeter |
| pH | Measure of the hydrogen ion activity |
| µS/cm | Microsiemens per centimeter |
| $yd^3$ | Cubic yards |

# EXECUTIVE SUMMARY

*Sargassum* spp., one of the dominant forms of marine macroalgae or brown algae (seaweed) found at beaches throughout Florida, is washing up on the shores in record quantities. Currently coastal municipalities are hauling and disposing of it in local landfills potentially wasting a valuable renewable resource. The City of Ft. Lauderdale has been implementing composting of *Sargassum* for the past 13 years. There has not been a formal cost analysis completed for their operation. Municipalities around South Florida implement various beach cleaning methods for *Sargassum*, as there is no one solution to the inundations. In order to compare the various methods that are employed, interviews were conducted with municipalities and organic growers to compile pertinent information for this study. The objective of this proposal was to assess the feasibility of a full scale seaweed compost system. We performed a cost analysis on the operation that Ft. Lauderdale has been running, and examined the logistics behind the operation. A market comparison of *Sargassum* compost was completed by examining the markets for substitute products for seaweed compost to determine the potential revenue from the sale of the compost.

We compiled the *Sargassum* management strategies that are employed through interviews with beach managers. The management solutions included composting, deep burial/integration/pull bar, leaving it on the sand when the quanties are small, and hiring third parties to collect and haul to a landfill. Results show that composting of *Sargassum* represents a potentially economically viable option for managing compost by municipalities and beach managers. When interviewing organic growers, there were concerns about the compost quality that was produced. Specific concerns were associated with nutrients and contaminants, such as plastics and arsenic. These are some of the concerns that need to be assessed before implementation of a *Sargassum* composting operation.

In summary, *Sargassum* composting provides an alternative to landfilling and has the potential to recoup costs for a municipality if it were to be sold. The fact that a useable product can be produced should elicit the need for new standards be developed specifically for compost made from *Sargassum*. Overall, the results from this study can be useful for municipalities as well as legislators in the State of Florida when making decisions on options to handle large *Sargassum* inundations which are anticipated to continue in the future.

# CHAPTER I

# MOTIVATION, OBJECTIVES, AND BACKGROUND

# CHAPTER I

# MOTIVATION, OBJECTIVES, & BACKGROUND

This chapter focuses on describing the motivation and objectives (Section I.1) and the project background (Section I.2) for this study.

## I.1 Motivation and Objectives

*Sargassum* is a genus of brown macroalgae or seaweed that includes over 300 species. Specifically, *Sargassum fluitans* and *S. natans* are species of pelagic brown seaweeds that are known to inundate the shores of the Caribbean, western Africa, and coastal cities of the U.S. (Langin, 2018; Milledge et al., 2016; LaPointe et al., 2021). These massive strandings have left municipalities unable to deal with the problem. During our Year 1 Hinkley Center funded research, we learned about Ft. Lauderdale's beach management strategy. Ft. Lauderdale has implemented a unique and sustainable practice of composting. For the past 13 years, Ft. Lauderdale has implemented this practice, which has been successful in removing the large strandings of *Sargassum* at the beach and have fine-tuned the process controlling smaller deposits to optimize beach ecology and aesthetics. Municipalities around South Florida deal with *Sargassum* management differently. From composting to removal to landfill. If other municipalities around South Florida were to follow suit with this example, there will be more space in landfills and a maintained tourist appeal for beaches. Cost analysis of Ft. Lauderdale's *Sargassum* composting operation had not formally been completed prior to the current study. With the framework already implemented by Ft. Lauderdale, other municipalities can potentially follow suite if this *Sargassum* management solution proves to be economically beneficial.

The objective of this proposal was to assess the feasibility of a full scale seaweed compost system, which limits the burden on landfills. Phase I (Cost Analysis) focused on performing a cost analysis on the operation that Ft. Lauderdale has been running and examined the logistics behind the operation. Phase II (Evaluation of *Sargassum* compost and alternate compost products) consolidated data from prior measurements of seaweed compost and compared it to the nutrient and pH characteristics of alternative compost products produced in the area. The samples collected as alternatives to *Sargassum* compost were analyzed for nutrients (N,P,K) and pH.

## I.2 Background

This proposal builds upon our "year 1" research project. Our year 1 research project focused on small scale experimental studies using compost tumbler systems and larger scale piles processed at the City of Hallandale Beach. The purpose of the new studies (year 2) was to perform a cost analysis on the *Sargassum* composting operation in the City of Ft. Lauderdale, which can used to justify implementation in other municipalities. The cost analysis provided details that can guide municipalities to establishing composting operations in their cities. As part of the cost analysis the research team examined the markets for substitute products for seaweed compost to determine the potential revenue from the sale of the compost.

Through the process of gathering information during the year-1 research project we learned about the large-scale compost operations in Ft. Lauderdale. Ft. Lauderdale grooms their beaches every morning and removes some of the seaweed from the shore, which generally coincides with a strong easterly wind and is most predominant during the summer season. Unwanted trash can be trapped in the seaweed as it floats in the water or as it is stranded on the shore. This trash can include but is not limited to plastic debris, shoes, nails, and wood. The seaweed when in excess along with the entrapped trash degrades the quality of the beaches for visitors and marine life, especially when the quantities stranded overwhelm the ecosystem.

***I.2.1 Ft. Lauderdale Composting Facility***

For the past 13 years, crews have been collecting and removing seaweed from Ft. Lauderdale's beaches using a Barber Surf Rake pulled by tractors (Figure 1). Once the Barber Surf Rake is filled, it is emptied in 8 cubic yard trucks, which are then brought to the compost processing facility located at Snyder Park in Ft. Lauderdale. An official cost analysis has not been run on the current operations. Rough estimates from 2010 to 2019 show that a total of 24,650 cubic yards have been trucked from the beach to the compost piles. This equates to about 3,081 truck loads each of 8 cubic yards. To dispose of 1 truck load of seaweed costs roughly $500, which brings the total to $1.54 million savings in landfill tipping fees and 24,650 cubic yards of saved landfill space. The seaweed compost is utilized by the municipality for public areas requiring new fill soil. Every three months, about 200 cubic yards of soil (cured *Sargassum* compost) are used for municipal landscape projects within the City of Ft. Lauderdale.

Ft. Lauderdale used to dispose of their debris at the Republic Services Envirocycle Recycling Center. Over the years, Ft. Lauderdale has invested in machinery, and thus all of their seaweed collection and processing operations are handled in house.


*Figure I.1- Barber Surf Rake bucket, where the seaweed is collected. B) Inside of the Barber Surf Rake. C) 8 $yd^3$ trucks used to empty the Barber Surf Rake. D) Compost pile at Snyder Park.*

# CHAPTER II

## Assessment of *Sargassum* Management Strategies in Southeast Florida

# CHAPTER II

# Assessment of *Sargassum* spp. Management Strategies in Southeast Florida

## II.1 Introduction

Seaweed, specifically *Sargassum* spp., and referred in this paper as *Sargassum*, is a genus of brown macroalgae that is known to inundate the shores of the coastal United States. Studies have shown that these annual blooms are expected to continue into the foreseeable future and will become the "new normal" for areas that are impacted (Wang et al., 2019; Salter et al., 2020; Machado et al., 2022; Trench et al., 2022; Tomenchok et al., 2021). In fact, at the writing of this manuscript record-breaking amounts of *Sargassum* have been quantified in the Atlantic Ocean with predictions for massive influxes for the summer of 2023 (Miller, 2023).

Coastal communities view *Sargassum* as a nuisance and are looking for ways to minimize the impacts from inundations (van Tussenbroek et al., 2017). Once onshore, these large inundations have been a challenge for beach managers. Beach managers, in most cases, have to apply for permits to remove and haul the *Sargassum* once onshore. The decomposition of *Sargassum* removes oxygen from the surrounding waters, killing fish and other marine life (Hallegraeff, 2010). Seagrass beds are also known to suffer losses due to *Sargassum* blocking light from the surface (Bartlett & Elmer, 2021). Not only does marine life become affected, but human health is also at risk. When in excessively large quantities and if left unmanaged on shore, *Sargassum* will decompose anaerobically often emitting a foul odor which can also be toxic (Resiere et al., 2018; Dominguez & Loret, 2019). Additionally, with large inundations of *Sargassum*, plastic waste that can be found in the open ocean and onshore, can get entangled within strandings.

In order to dispose of the large inundations of *Sargassum*, waste managers often haul it to landfills when inundations are excessive. Hauling *Sargassum* to landfills can be viewed as an unnecessary cost, given the possibility of its beneficial uses (van Tussenbroek et al., 2017). Sustainable alternatives, such as composting, may be a viable option. Indeed, the compost itself may be marketable and allow beach managers to recoup some of the *Sargassum* compost production costs (Gajalakshmi & Abbasi, 2008; Kumar, 2011). Even though the large inundations are considered a nuisance, *Sargassum* can viewed as a resource (Milledge & Harvey, 2016; Chávez et al., 2020; Amador-Castro et al., 2021; Trench et al., 2022). In a study conducted by Sembera et al. (2018), food waste and wood chips were mixed with *Sargassum* (unwashed and washed). Even though a usable product was created and met the standards outlined by the U.S Composting Council (USCC) in terms of plant nutrients (nitrogen, phosphorus, and potassium specifically), the proportion of *Sargassum* used in the compost product was small (2%), which limits the amount of useable *Sargassum*. In another study conducted by Walsh and Waliczek (2020), larger proportions (25% or 41.5%) of *Sargassum* were used in a large-scale composting system to assess the quality of the product for utilization in agriculture. The compost produced also met the guidelines outlined by the USCC. Our team recently completed studies evaluating compost ranging from 50% to 100% *Sargassum.* Our study showed that the compost produced was capable of sustaining the growth of radishes. However, nutrient levels were not optimal, plus bacteria and arsenic levels occasionally failed regulatory guidelines thereby limiting some beneficial uses. To our knowledge, there has been only one additional study conducted that composted pure *Sargassum* but in the sole context of mangrove restoration (Trench et al., 2022). Further research is needed on the operational analysis to assess the viability of compost production by beach managers or small enterprises, especially when *Sargassum* quantities are high and the availability of additional feedstocks are limited. Research is needed to assess the economic viability of composting, especially when beneficial uses may be limited due to regulatory constraints.

This study assessed the *Sargassum* management strategies in southeast Florida and compared these strategies against a government agency that employs composting of *Sargassum* to better assess the economic viability of the *Sargassum* composting processes. We conducted semi-structured interviews with key informants, beach managers and potential users, to assess the difference in beach management strategies and uses of the *Sargassum*. We then evaluated the costs and conducted a market analysis to compare *Sargassum* compost against other compost alternatives.

## II.2 Methods

### *II.2.1 Interviews with Beach Managers and Potential Compost Users*

A two-person research team using pre-written questionnaires conducted semi-structured interviews in 2021 and 2022 with key informants. The key informants were split into two categories, each category with its own corresponding questionnaire. The first category consisted of beach managers and the other consisted of potential compost users. In brief, the pre-written questionnaire for beach managers asked about beach management and practices (specifically of *Sargassum*), interest and experience in composting *Sargassum*, and costs associated with beach management. The responses from this questionnaire were organized to compare beach management objectives, size of area managed, *Sargassum* management (during peak and off season), and communication of the strategy. The strategies used by the agencies were also ranked by the research team (high, medium, low) in terms of cost effectiveness, environmentally friendliness, manageability, and beach appeal. The pre-written questionnaire for the potential compost users focused interest in *Sargassum* compost product and for those that produced their own compost, composting techniques used. The responses from this questionnaire were used for a market analysis. Copies of the questionnaires are provided in the supplemental material.

Beach managers included individuals from local government agencies that handle the maintenance of beaches in southeast Florida. Beach managers interviewed described various methods of management of *Sargassum* implemented years prior to this study. A total of six beach managers were interviewed representing four agencies. The first three agencies were represented by one beach manager each. The fourth agency was represented by three beach managers. Composting was the primary management strategy for the first agency. A detailed cost analysis was conducted for Agency 1 to assess the costs of their operations. The strategies and operations of the remaining three agencies were compared against the first agency. Field visits were also conducted for some of the agencies (Agency 1, Agency 2, and Agency 4).

The second category of informants interviewed, consisting of potential compost users, included four organic growers and one local liquid fertilizer business. In addition to the questionnaires, field visits were conducted with the organic growers. For the market analysis (described below), samples of alternative composts produced by three of the four organic growers were also collected for nutrient analysis (nitrogen, phosphorus, and potassium) for comparison with nutrients associated with *Sargassum* compost. Samples were not available from the local business. The responses to these questions provided us with information about the value associated with alternatives to *Sargassum* compost. At the conclusion of each set of interviews, the key informants were asked about drawbacks and limitations associated with composting. These responses were summarized in tabular form.

### *II.2.2 Cost and Market Analysis*

For the cost analysis, as mentioned above, Agency 1 utilized composting as its primary management strategy for *Sargassum*. For Agency 1, we created an enterprise budget for composting *Sargassum*, using accepted methods (Wentworth et al. 2002; Zurbrügg et al. 2005; Chen 2016). This budget included all the costs involved in managing the compost pile (i.e., labor, machinery operating and depreciation costs, land rental values, and return on capital). We then compared Agency 1's total cost to compost the *Sargassum* to the cost that nearby local governments (Agencies 2 through 4) spent to remove and dispose of the seaweed found on their beaches.

For the market analysis, we compared two factors: 1) the quality of the compost product for growing plants, as expressed by nutrient measurements (N, P, and K) plus pH, and 2) the pricing of the compost products on the market. To expand on the description in the introduction, during an earlier study (Abdool-Ghany et al., in review), we composted *Sargassum* using 6 different recipes (unwashed *Sargassum*, washed *Sargassum*, *Sargassum* plus grass clippings, *Sargassum* plus mulch, outdoor *Sargassum*, outdoor *Sargassum* plus vegetative waste). Details about the production and properties of the compost produced from these recipes are described by Abdool-Ghany et al. (in review) with some additional details also included in the supplemental text of the current study.

We report here the N, P, K values and pH for these six recipes along with the N, P, and K values and pH of compost products that were gathered from the farms of organic growers that were interviewed for the market analysis. The compost samples provided were made from: a) food and mulch, b) compost combined with chicken manure, garden soil, and c) garden soil and plant biomass. Whereas the process of measuring N, P, and K in our earlier study is described in detail in Abdool-Ghany et al. (in review), the N, P, and K values of the samples collected from the organic growers were sent to a commercial laboratory (A &L Great Lakes Laboratories, Fort Wayne, Indiana) and as detailed in the supplemental text analyzed by standard protocols (Test Methods for Examination of Compost and Composting (TMECC) by the USCC.

As no market currently exists for *Sargassum* compost, we estimated its value by first comparing the nutrients of *Sargassum* compost combinations against compost produced from the alternative organic materials. We then used the price of similar nutrient quality products as described by the organic growers which they either purchased from third party sources or sold to other local growers. Similar comparative market analyses have been employed to place a monetary value on compost and other products that are currently unavailable in the market (Wentworth et al., 2002; Waliczek et al., 2020). Unlike the Waliczek et al. (2020) study which was based on a hypothetical scenario to estimate the price for *Sargassum* compost, based on what consumers said they were willing to pay for it, our study makes a direct price comparison to compost products already in the market . This market comparison allowed us to obtain a range of potential market values for each of the compost recipes based on the market prices supplied by the local growers.

### *II.2.3 Statistical Analysis*

In order to determine the normality of the data, a Shapiro-Wilk test was performed on the *Sargassum* compost treatments and the organic compost samples collected. It was determined that the data was normally distributed, thus parametric tests were used to compare the N, P, K, and pH values for the *Sargassum* compost treatments and the organic compost samples. Independent t-tests were used to compare the two sets of data. Differences were considered statistically different for $p$ values less than 0.05.

## II.3 Results and Discussion

### *II.3.1 Analysis of Management Strategies*

The agencies that were interviewed differed in beach management objective, management area, management strategies, and mode of communication with stakeholders (Table 1). Agencies 1, 2, and 4 were concerned about the aesthetics of the beach and wanted to make sure it looked pristine, whereas Agency 3 was more concerned about ecological preservation. Agency 4 managed the largest beach areas, while Agency 2 managed the smallest. The five main *Sargassum* management practices included composting (Agency 1), deep burial (Agency 2), pull bar (Agency 3), cut and turn (Agency 4), and hauling away to landfill when in excess (Agency 2 and 4).

Composting as used by Agency 1 is described as allowing the *Sargassum* to decompose overtime within a dedicated heap. The *Sargassum* is then moved to various places in the compost heap to control the decomposition as more *Sargassum* is brought in. *Sargassum* that is brought in from the beach is placed in designated areas for fresh *Sargassum.* As the *Sargassum* that is brought in decomposes, it is then moved to other areas of the pile to make room for fresher *Sargassum* that is washed onshore. Deep burial is the process by which a 3 to 4 foot pit is created on the beach and then filled back with *Sargassum*. This pit is then covered with sand and the *Sargassum* decomposes within the pit. Pull bar and cut and turn are very similar strategies and differ in the amount of disturbance to the *Sargassum*. With the pull bar strategy, a bar is attached to a tractor and pulled across the top of the beach. The *Sargassum* is tilled into the top layer of the sand but is minimally broken down by mechanical processes. It results in the least disturbance to the beach. Cut and turn is similar to the pull bar strategy in that the *Sargassum* is tilled into the sand, but this process involves breaking the *Sargassum* into smaller pieces. With both cases, the *Sargassum* is integrated into the sand and creates a sand/*Sargassum* mixture.

As studies have shown that integrated *Sargassum* contributes towards fecal indicator bacteria contamination of coastal waters, deep burial is utilized in some areas to try to minimize the concentration of bacteria in the nearshore water (Abdool-Ghany et al., 2022). Agency 4 also utilizes decomposition as a strategy to manage *Sargassum* when the inundations are excessive. With this process, the *Sargassum* is removed from the beach to a staging area and allowed to dry and decompose. During peak season, when the inundations are massive, the most common management method is to collect the *Sargassum* on the beach and haul it away to a landfill, which is usually done by a third-party company. All four agencies use websites as their main form of communication with the public about *Sargassum.* Agencies 3 and 4 are the only ones that use signs posted in various locations along their beaches to inform beachgoers about *Sargassum*.

We compared the management strategies employed by each Agency across four parameters, beach appeal, environmental friendliness, manageability, and cost effectiveness (Table 2). Most of the Agencies are concerned about keeping and maintaining the beaches pristine. For beach appeal, we rated Agencies 1, 2 and 4 as high due to their objective of beach management. All three of the Agencies want beaches that meet tourist expectations of white sandy beaches since tourism is an important industry to the local economy.

Agency 3 viewed the *Sargassum* onshore as being beneficial and a natural occurrence when quantities are not high, we ranked it as high in the environmentally friendly category. When the *Sargassum* is not removed from the beach, the sand is not white anymore and can be a concern to tourists. The beach manager in Agency 3 mentioned that the beach is a, "Functioning ecosystem and there are plants there." So, education for Agency 3 is the best tool other than removing the *Sargassum* on the beach. In order for the patrons of the beach to see it as such Agency 3, "Provides more education when necessary." Agency 3 will, "Up the ability to answer phones called and provide education on *Sargassum*" when there are large influxes, since this agency does not remove any of the *Sargassum*. Until there is a more environmentally friendly solution, Agency 3 decided it was, "Not going to remove it [*Sargassum*] until there is a solution. Even if it will be removed, it won't be every day." Agency 2, on the other hand, prioritizes maintaining the beach in pristine condition, but acknowledged that this prioritization is not the most cost-effective or environmentally friendly. They would rather, "Turn a waste into resource," which in turn is more environmentally friendly than taking the *Sargassum* to a landfill. Agency 1 also desired to keep the beaches clean and pristine but composted the *Sargassum* that makes its way onshore. When compost produced by Agency 1 is ready to be used by the city, additional mechanical processes are used to remove large plastic debris that is entrained. The compost that was created by Agency 1 was used as fill in medians across the city. It was, "Just put into the ground." They noted that the plants in these public spaces that had *Sargassum* compost as soil amendment "grew so fast."

We rated Agency 2's strategy on manageability as being high. Outsourcing beach cleaning was very costly, but it also offered a manageable solution, as the agency did not have to be concerned with coordinating the logistics. Agency 1 was rated as low for manageability since composting operations were managed internally and all operations were conducted in-house, which required the Agency to undertake coordination and logistical activities. Although the manageability was ranked low for Agency 1, the manager from the agency was happy with the process. The manager explained that the Agency, "Can't help but win with this one." Agency 4 has found a happy medium of outsourcing removal, "From what is called hotspots" along the beaches, while sporadically cleaning the remaining beaches in-house.

The fact that the beach managers have different procedures to address *Sargassum* influxes provide us with an opportunity to make comparisons of the strategies in terms of their cost-effectiveness. We compared the strategies of the other Agencies to Agency 1, which used composting. Agency 1 cleaned the coastline every day and the collected *Sargassum* was hauled away to a local park. The *Sargassum* composting operation by Agency 1 was run in-house using their own equipment and employees. While the Agencies were concerned about maintaining their beaches in pristine conditions, they also had to meet budgetary constraints. A local waste management official from Agency 2 pointed out that they had: "Desire to deal with this in a cost-effective way." Cleaning the beach by hauling *Sargassum* to a landfill was the costliest strategy, especially during large inundations. The representative from Agency 2 described it as, "Take $445,000 put it in a dump, throw a little gasoline in there and light a match." This was for an instance when the agency received large amount of *Sargassum* onshore. For two of four managers, the costs associated with outsourcing during heavy seasons was voiced as a concern.

Composting and cleaning the beaches in house is much more cost effective, as implemented by Agency 1 and Agency 3.

*Table II.1-Description of beach management strategies, objectives, size of areas managed, and communication methods for agencies that manage Sargassum at beaches in southeast Florida.*

| Agency | Agency 1 | Agency 2 | Agency 3 | Agency 4 |
|---|---|---|---|---|
| **Beach Management Objective** | Concerned about the aesthetics of the beach | Concerned about the bacteria levels and aesthetics of the beach | Not concerned about a pristine beach but also about the ecology preservation of the area | Maintaining the aesthetics of the beach as it is important for tourism |
| **Size of area managed** | Approximately 6.4 km | Approximately 2.0 km | Approximately 3.5 km | Approximately 27.4 km |
| ***Sargassum* Management During Off-Peak Season** | Composting<br>Seaweed is removed and transported to an off-site compost pile | Deep burial of seaweed 3-4 feet and capped with a layer of sand | Pull bar used to till *Sargassum* into the sand and used to minimize beach disturbance | Cut and turn strategy is used along some beaches |
| ***Sargassum* Management During Peak Season** | Composting | Deep burial in addition to hauling away to a landfill | Pull bar | Relocating *Sargassum* to a staging area that allows for decomposition<br>Haul away to landfill from hotspot areas |
| **Communication Strategy** | Provides information to the public via website about the seaweed composting efforts.<br>Includes information about how much is saved, and statement of sustainability | Provides information to the public via website, which offers information on the management style used and detailed explanation as to why it is chosen | Provides information to the public via website as well as public signage along the beach.<br>Website and signs provide information on the ecological importance of *Sargassum* | Provides information to the public via website as well as public signage along the beach.<br>Website provides a Q&A format for information.<br>Signage is simple and briefly explains what *Sargassum* is |

*Table II.2- Ratings of high, medium, and low of the viability assessment across the agencies*

| Agency | Beach Appeal | Environmentally Friendly | Manageability | Cost Effectiveness |
|---|---|---|---|---|
| **Agency 1** | *High* Keeps beach looking pristine | *Medium* Energy expended to keep beaches pristine to take to composting facility | *Low* Operations in house which requires a high level of coordination | *High* Has own composting operation with all machinery and land |
| **Agency 2** | *High* Keeps beach looking pristine | *Low* High energy use to clean beach and using landfill space | *High* Managed by a third party which requires a lower level of coordination | *Low* Outsourcing to third party is costly when there are large inundations. Cost is reliant on the number of truckloads and tipping fees |
| **Agency 3** | *Low* Beach not pristine with black compost mixed in with white sand | *High* Leaves on the beach and tills in | *Medium* Operations in house, limited activities outsourced to a third party | *High* Has own machinery and maintains beach in house |
| **Agency 4** | *High* Keeps beach looking pristine with a staging area that is out of view of beach goers | *Medium* High energy use and space for portion sent to landfill but less energy intensive for portion that is buried | *Medium* Outsourcing of hotspots requires little management but some for sporadic cleaning of remaining beaches | *Medium* Costly for the portion that is removed and deposited into landfills but less for the beaches where *Sargassum* is staged nearby |

### *II.3.2 Cost and Market Analysis*

There are two primary costs associated with running a *Sargassum* compost operation. The first is the cost of beach cleaning and hauling which by Agency 1 was estimated at $308,800 per year. The second cost is associated with the operation of the compost pile. We estimated that Agency 1 spends US $78,100 per year to operate its *Sargassum* compost pile. These costs include $53,800 for the bulldozer, $10,600 for the shaker, $13,000 in personnel costs, and $700 for land (See Blare et al. 2023 for details).

If Agency 1 did not have a composting operation, they could dispose of the *Sargassum* in a landfill. Before Agency 1 started composting *Sargassum* in 2010, they spent $200,000 annually on disposal costs, which included the tipping fees and transportation costs to take the *Sargassum* to the landfill, the practice utilized by Agency 2 during peak *Sargassum* season. When indexed to inflation, according to the U.S. Consumer Price Index, the $200,000 costs for Agency 1 to dispose *Sargassum* in a landfill would be valued at $260,000 in 2022. However, many of these costs have likely increased a faster rate than inflation. The actual cost to Agency 1 if it were to revert to this former strategy would likely be larger than $260,000. Prior to Agency 1 establishing its own composting operation, the costs in any given year varied depending on the amount of *Sargassum* onshore and the truckloads used to haul it to a landfill. Since composting is now conducted in-house at Agency 1, the costs are more stable given that they no longer pay tipping fees and the hauling to the compost facility is completed with existing equipment.
For a better comparison to determine which practice (composting or landfilling) is most costly, we compared the per cubic yard cost that Agency 2 spent on *Sargassum* disposal in 2020 to estimate what that cost would have been for Agency 1 if it had decided to dispose of the *Sargassum* in the landfill. Agency 2 spent around $300,000 to dispose of 3500 $yd^3$ of *Sargassum* in 2020, which is $86 per $yd^3$. Considering that Agency 1 collected 4721 $yd^3$ off its beaches in 2019, the Agency potentially would have spent nearly $406,000 to dispose of the *Sargassum* in 2020, which is more than 5 times the cost to operate the composting facility ($78,100 per year) and higher than the $260,000 low end landfilling cost described above. We estimate that by investing in the composting facility Agency 1 saved around $326,000 that would have been spent to dispose of the *Sargassum.* Agency 1 also used the compost it produced as fill to meet its landscaping needs in its parks and roadways. Purchasing this fill would have cost the city between $2000 and $3000. Thus, we project that Agency 1 saved nearly $328,000 by composting the *Sargassum* in 2021.

Samples that were used for the market analysis were collected from 6 *Sargassum* compost samples we created as part of a prior study (Abdool-Ghany et al., in review) and another 3 were collected from the organic growers we interviewed. Samples were analyzed for nitrogen, phosphorus, potassium, and pH. For the 6 *Sargassum* compost treatments that we created, composted, and tested, the N values ranged from 0.748-1.263 % by weight (Table 3). Treatments from the large-scale experiments tended to have higher N values than the small-scale treatments. Phosphorus values ranged from 0.043- 0.152 % by weight. Treatments with grass clippings and vegetative waste tended to have higher P values. Potassium ranged from 0.061-0.391 % by weight. The treatment with 100% unwashed *Sargassum* as well as mulch in the small-scale experiments had higher K values, with values of 0.391 and 0.381 % by weight. The pH ranged from 8.91-9.77. Lower pH levels were measured in 100% *Sargassum* compost from the large-scale experiments compared to those created using the tumbler composters.

*Table II.3- N-P-K and pH values of the compost. Data provided for compost produced within the small- and large-scale experiments by the researchers and for compost provided by organic growers.*

| | Sample Treatment | N % by weight | P % by weight | K % by weight | pH | Price (per $yd^3$) |
|---|---|---|---|---|---|---|
| Small-Scale (Tumbler Composters) | 100% Unwashed *Sargassum* | 0.991 | 0.052 | 0.391 | 9.64 | - |
| | 100% Washed *Sargassum* | 0.754 | 0.043 | 0.238 | 9.77 | - |
| | 80% *Sargassum* and 20% Grass Clipping | 1.102 | 0.121 | 0.183 | 8.91 | - |
| | 92% *Sargassum* and 8% Mulch | 0.748 | 0.060 | 0.381 | 9.63 | - |
| Large-Scale (Compost Piles) | 100% Unwashed *Sargassum* | 1.097 | 0.054 | 0.061 | 9.26 | - |
| | 57 % *Sargassum* and 43% Vegetative Waste | 1.263 | 0.152 | 0.108 | 9.17 | - |
| Organic Compost | Food and Mulch | 0.640 | 0.090 | 0.140 | 7.84 | $810 |
| | Compost combined with Chicken Manure | 0.960 | 0.150 | 0.510 | 8.09 | $35 |
| | Garden Soil | 1.100 | 0.050 | 0.180 | 8.11 | $182 |
| | Garden Soil Mixed with Plant Biomass | 1.030 | 0.070 | 0.230 | 8.31 | - |

For the four compost samples provided by the organic growers (Table 3), N ranged from 0.640 to 1.100, P ranged from 0.050 to 0.150, and K ranged from 0.140 to 0.510. Finally, the pH ranged from 7.84 to 8.31. There were some similarities when comparing the *Sargassum* compost to the organic compost collected from the organic growers. The N values for the compost in the large-scale 100% Unwashed *Sargassum* treatment had a value of 1.097 and in the small-scale 100% Unwashed *Sargassum* treatment had a value of 0.991. This is very close to the values that were measured for the compost combined with chicken manure , garden soil, and the garden soil mixed with plant biomass compost, which had a value of 0.960, 1.100, and 1.030 respectively. P and K values for all the *Sargassum* compost treatments were also similar to that of the organic compost. In the *Sargassum* compost treatments, the treatment with 57% *Sargassum* and 43% vegetative waste had a P value of 0.152. The organic compost made from cut with chicken manure had a P value of 0.150. Compost combined with chicken manure also had the highest K value of 0.510, while all other compost samples, both *Sargassum* and organic composts, were similar. This study found that the *Sargassum* compost treatments were not statically different than the organic compost products collected for all three nutrients values of N ($p=0.662$), P ($p=0.744$), and K ($p=0.704$). In terms of the pH, *Sargassum* composts were more basic compared to the compost provided by the organic growers. The compost made of food and mulch exhibited the lowest pH of 7.84, while the highest pH was detected in the 100% washed *Sargassum* with a value of 9.77. Overall, the pH values from the *Sargassum* compost treatment and the organic compost samples collected were statistically significantly different ($p=<0.0001$).

Considering that Agency 1 collected 4721 $yd^3$ of *Sargassum* in 2020 and that from our composting testing we found that freshly collected *Sargassum* is 90% water, we estimate that the agency would have produced 472 $yd^3$ of compost. We define fresh *Sargassum* based on the moisture content. A fresh sample of *Sargassum* can normally have a moisture content of greater than 75%. Compared to the value of the composts produced and used by growers in south Florida that have a similar nutrient composition ($800 per $yd^3$), we estimate that *Sargassum* compost produced by Agency 1 to be worth as much as $377,600, which would indicate that if Agency 1 were able to sell its compost at this rate it would be able to recoup nearly all the costs to clean the beach estimated to be $308,754 and to operate the compost pile, which costs $78,118.

Results from the interviews indicated that not only are contaminants a concern for beach manager, but they are also a concern for potential users of *Sargassum* compost. Since entrainment of plastics is a drawback of the *Sargassum* compost produced by Agency 1, buyers are unlikely to value this compost as much as that made by local growers which does not contain visible entrained plastics (Table 4). From the interview conducted with the local business owner, he noted that "It's [*Sargassum*] filled with plastics" as it makes its way on shore. Even if the *Sargassum* compost from Agency 1 were valued at half the price of the high-quality compost produced by local growers, it would still be worth $188,800, more than double the cost to manage the compost pile. Also, during the interview process, land space for composting was voiced as a concern by two of the four beach managers interviewed.

One compost operator mentioned that *Sargassum* compost is undervalued in the commercial market because of its lower NPK values. This compost operator states that measurements of NPK values do not consider all the additional benefits provided by compost. She explained that compost, "Doesn't have to have a high NPK value. What matters is what the plant needs." The microorganisms found in compost are essential to soil health and, thus, plant vigor. She explained that, "Seaweed is known to be an amazing fertilizer for plants." This is also supported with the liquid fertilizer that is produced with the  local business owner. The local business owner mentioned that the compost product "Can be used on just about anything" given the nutrient content. As growers and gardeners begin to realize this additional value of *Sargassum*, they would likely be willing to pay for it, providing an economic boom for agencies that compost it.

Overall, the results from the cost and market analysis suggest that the economics favor composting *Sargassum* over disposal in a landfill. The potential value generated from composting, if there is a market to sell the product, could possibly be used to offset the cost of grooming the beach. Perceptions by potential users of the *Sargassum* compost vary, some in favor and others recognizing limitations.

*Table II.4- Drawbacks and Limitations of Sargassum Compost as Identified by the Key Informants*

| Drawback and Limitations |
|---|
| • Land space for composting operation<br>• Contaminants such as heavy metals, mainly arsenic, and large debris made of plastics<br>• During peak season, the cost that is associated with outsourcing the Sargassum management<br>• Permitting limitations from government agencies<br>• Contaminants such as heavy metals, mainly arsenic, and microplastics |

### *II.3.3 Discussion*

When comparing managing a composting operation (Agency 1) to disposing *Sargassum* in a landfill (Agency 2), composting this material appears to be a cost and environmentally friendly alternative that can be used to ensure a pristine beach. However, operating a compost facility requires greater management and coordination than outsourcing beach cleanup through landfilling. It also requires the capital to invest in creating the facility, purchasing the equipment and access to land. While integrating the *Sargassum* into the beach sand (Agencies 3 and 4) proved to be a cost-effective alternative to manage *Sargassum* influxes (when the quantities are not large), the result can leave the beaches looking less like the idealized white sand beaches expected by many tourists. If beach appearance is not a concern, the strategy of integrating the *Sargassum* would seem to be the best alternative. Nonetheless, the sale of compost may help offset the costs of cleaning the beach and provide an important fertilizer and soil amendment to local growers and gardeners. One study conducted by Waliczek et al. (2020) examined participants' willingness to buy *Sargassum* compost. They found that there is a potential for specialty seaweed-incorporated compost in the retail market. Participants were willing to pay \$4.00/ft$^3$ (\$110/ yd$^3$) to \$5.00/ft$^3$ (\$135/ yd$^3$) for seaweed-incorporated compost. Without production cost estimates, waste management operators are unsure if the sales of this compost at this price would cover their expenses. Thus, they would be unwilling to take the risk of investing in more expensive *Sargassum* composting facilities if they are not guaranteed a return on their investment or a reduction in overall costs. Unfortunately, in highly urbanized areas, like in Southeast Florida, there may not be affordable land, especially with rapidly increasing land prices, to run a large-scale composting facility or at least land close to the beach to minimize the hauling distance of heavy, wet *Sargassum* (Qiu, 2022).

For these agencies and any others that are evaluating the production of *Sargassum* compost as a management strategy, they will likely have to work with policymakers to ensure that they have permission to conduct such activities. Currently under Florida Administrative Code (FAC), chapter 62-709, *Sargassum* can be composted under the Source-Separated Organics Processing Facility (SOPF) registration program. In 2010 it was determined that the *Sargassum* that washes onshore was “yard trash” (FDEP, 2010). This status was determined in part by the composting operation established by Agency 1. This has allowed Agency 1 to compost *Sargassum* under the registration program. Since the amount of *Sargassum* has increased over the last decade and the issue is now impacting more municipalities across Florida, FDEP is proposing to update Chapter 62-709, FAC to officially list *Sargassum* with its own definition and with limited end uses.

The experience of these Agencies in Southeast Florida in managing their *Sargassum* influxes provide lessons for other areas affected by *Sargassum* and other seaweed influxes as well as the general management of organic materials. However, what a local government agency believes is composting and what organic growers consider compost can differ. Organic growers follow stringent composting guidelines as required by the state such as reaching a certain temperature for a given time period. Commercial composting operations are required to maintain a temperature of at least 131°F for at least 15 days (FDEP, 2010). Compost made from fecal waste or manure requires strict temperature requirements. Whereas *Sargassum* is not a fecal waste, so a strict temperature requirement may not be necessary. This strict temperature requirement is needed for manure in order to ensure that pathogens are inactivated from the source material. From our previous study (Abdool-Ghany et al., in review), this temperature guideline was not achieved for the outdoor piles created. However, bacteria concentrations were within recommended limits for compost made outdoors.

To have usable compost that can be sold, it must be free of contaminants, such as plastic debris and arsenic. One major concern brought to our attention by one of the organic growers was microplastics in addition to macro or large plastic debris pieces. Microplastics are less than 5 mm in size and come from debris that is entangled with the *Sargassum* (Carpenter & Smith, 1972). More than 5 trillion plastic particles are floating in the sea (Eriksen et al., 2014) and have become a common concern in the marine environment. Microplastics that are in the ocean can stick to many different species of macroalgae, especially *Sargassum* (Seng et al., 2020), which then makes its way onshore. Once onshore the *Sargassum* can pick up additional microplastics from activities on the beach (e.g., plastic bags from beach goers and plastic toys left behind). These entangled plastics are difficult to remove; thus, can end up in the final compost product. Compost products are known to have a large number of microplastics that can affect soil chemistry (Yu et al., 2022). Degrading plastics can become more poisonous as they can attract and bind to other man-made chemical pollutants (Kolluru et al., n.d). The quality of compost produced might not be what is expected and can limit its market potential.

Another contaminant that is of concern is arsenic, which can be found in high concentrations in *Sargassum* (Devault et al., 2020). This can pose a problem for composting of *Sargassum*. Johnson and Engel (2022) found that mixing potting soil with dried Sargassum resulted in higher arsenic levels in the plants produced. It was also found that arsenic levels in *Sargassum* compost did not meet regulatory guidelines outlined by the Florida Department of Environmental Protection (FDEP) Soil Cleanup Target Levels (SCTL) for residential use (Abdool-Ghany et al., in review). Concentrations were above the maximum allowed able limit of 2.1 mg/kg and were within the range of 6.64- 26.5 mg/kg.

There is interest in adding other waste streams to *Sargassum* to create a richer product with higher N, P, and K quantities. One promising opportunity is vermicomposting of *Sargassum* and food waste. Vermicomposting uses worms to convert organic waste into a soil amendment. Issues of contaminants such as microplastics and other toxic metals have the potential to be taken care of during this process if the *Sargassum* and other waste streams are pre-composted. Pre-composting is used in vermicomposting and allows for the material to be broken down before starting the vermicomposting process (Castillo-González et al., 2019). He et al. (2016) found that when using a combined composting -vermicomposting process in sewage sludge with additives (soil, straw, fly ash and sawdust), the heavy metal concentrations were lowered compared to the control without the additive. In a study by Patón et al. (2022), pre-composting, or allowing the material to decompose partially, can increase the rate at which the worms can process the material. In addition, there are other studies that produced a rich product by combining various seaweed types and cow manure as feedstocks for vermicomposting (Ananthavalli et al., 2019a, 2019b). However, more research is needed to understand the cost-effectiveness of this method. On the other hand, additional markets are growing for *Sargassum* derived fertilizers like liquid fertilizers. Much of the fertilizers made from seaweed are liquid fertilizers. Further analysis would be needed to understand the economic viability of creating these fertilizers. These fertilizers have a much higher value than compost. For instance, 8 oz of an organic blend of 7 species of seaweed can cost $14 from online retailers (Amazon, 2022).

*Sargassum* compost is likely to become more attractive because of increasing fertilizer costs, especially for inorganic fertilizers. With recent geopolitical instability and supply chain challenges associated with inorganic fertilizers, growers, nursery operators, landscapers, and even homeowners are finding it difficult to source affordable fertilizers. The price of fertilizer increased by 30% in first quarter of 2022, after jumping 80% the year before. There is little expectation that fertilizer prices will fall in the near term (Baffes and Koh, 2022). Because of these soaring prices, growers throughout the world are exploring alternatives to inorganic fertilizers, which have been the primary plant nutrient source for commercial growers since the 1950s. Many are exploring organic compost as an option to lower their costs while ensuring their crops receive the proper nutrients (Merrigan, 2022). This market reality is likely to make *Sargassum* composting, and composting of all organic material in general, a more financially attractive alternative. Based on all this evidence, this study suggests that waste managers should not overlook composting in their strategic planning when evaluating options to manage *Sargassum* inundations.

### *II.3.4 Limitations and Recommendations*

With contaminant concerns such as arsenic, there are limitations for the end use of the *Sargassum* compost. Regarding arsenic, specifically in South Florida, *S. fluitans* was observed to have arsenic concentrations ranging between 116-119 mg/kg while arsenic in *S. natans* varied between 90-103 mg/kg (Collado-Vides et al., 2020). The range of arsenic concentrations detected in the current study was 6.64-26.5 mg/kg. Although these values are lower than what was reported in the study listed above, it still exceeds the FDEP SCTL maximum concentration limit of 2.1 mg/kg and 12.0 mg/kg for residential and industrial use, respectively. However, it does pass the EPA guidelines for biosolids.

Alternatively there are other end uses for the *Sargassum* product that is created. The material shows promise for agricultural uses in non-food crop applications, such as ornamental plants. It may have other beneficial uses, such as in the restoration of mangrove forests and dunes, and possibly as fill material in coastal areas. We recommend additional research to further explore potential reductions of arsenic to widen the scope of uses for *Sargassum*, as the arsenic levels appear to hinder uses within residential applications.

In addition, we recommend research to further evaluate methods to move the *Sargassum* without negative impacts to the ecosystem inclusive of limiting the loss of sand. For example, the tradeoffs between potential impact to turtle nests versus the possibility of overwhelming the turtles with too much *Sargassum* needs to be evaluated. Furthermore, sifting of *Sargassum* from the beach may result in the loss of sand and more work is needed to explore various sifting devices. Removing of the *Sargassum* from the shore also removes some of the sand that is on the beach. Costs that are associated with this removal were not taken into consideration. Further experiments should focus on the costs that are associated with replacing the sand that is taken away when removing the *Sargassum*.

# CHAPTER III

# SUMMARY AND CONCLUSIONS

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### III.1 Summary and Conclusions

Overall, this study showed that a *Sargassum* composting operation does represent a potentially economically viable option for municipalities and beach managers. If the *Sargassum* compost that is produced meets the required guidelines by various agencies, such as the USCC, FDEP, and the US EPA, then there is the possibility that the compost can be sold to recoup the costs that are associated with beach cleaning.

In addition, there should be a broader view and more research in terms of evaluating the ecosystems and human health impacts due to the large inundations of *Sargassum* onshore. Future studies should examine the effects of the large inundations on turtles. Regarding human health, there is also concern for the exposure to hydrogen sulfide that can be released as the *Sargassum* decomposes.

### III.2 Recommendations

Results from this study can serve as a starting point for municipalities to begin their *Sargassum* composting operation. It also provides information for FDEP to consider when working on defining *Sargassum* in Chapter 62-709, F.A.C. As the FDEP is working on defining *Sargassum*, they are also looking to require specific standards for compost made of *Sargassum*. This would help in unifying the standards that should be met. This is particularly important for arsenic as regulatory limits for arsenic vary widely. Given the promising results from this study and a previous HCSHWM funded study, the arsenic concentrations in *Sargassum* should be carefully examined.

### III.3 Practical Benefits for End Users

Working with *Sargassum* to produce compost allows for this valuable resource to serve a useful purpose. It helps the solid waste industry by diverting this potential resource from landfills, thereby freeing up landfill space. Furthermore, it also provides cities and other municipalities the opportunity for financial savings by eliminating the need to haul the seaweed to landfills and pay landfill tipping fees. This study will be useful to beach managers and County Parks and Recreation Departments by providing a beneficial and potentially financially viable option for managing *Sargassum* after large strandings, thereby reducing costs associated with maintaining beaches. This project can also benefit the tourism industry in Florida by improving the viability of *Sargassum* removal during times that it is detrimental to the local ecosystems, especially during times of extreme *Sargassum* strandings which result in turtle die-offs and production of hydrogen sulfide from rotting *Sargassum* on the beach. The insights from this project will also benefit the community at large through the provision of a new compost material for gardening.

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# Appendix A

# Questionnaires used in Interview Process

## Questionnaire sent out to Beach Managers

### 0. Screening

| |
|---|
| *0.1 Do you work for a private firm (i.e. Company) that addresses Sargassum removal from beaches?* |
| ☐ Yes<br>☐ No |
| *0.2 Do you work for a public firm ( i.e. government agency) that addresses Sargassum removal from beaches?* |
| ☐ Yes<br>☐ No |
| *0.3 Do you wish to remain anonymous in terms of your answers or can we disclose your name?* |
| ☐ Yes<br>☐ No |

### 1. Introduction

| |
|---|
| 1.1 What is your position? |
| 1.2 How long have you held this position? |
| 1.3 What are your responsibilities in this role? |
| 1.4 How does it relate to the management of Sargassum? |

### 2. Sargassum Management Practices

| |
|---|
| 2.1 How is Sargassum/seaweed managed at your beach sites? |
| 2.2 Under what conditions is the Sargassum moved from its natural stranding location? |
| 2.3 Under what conditions is it hauled away? |
| 2.4 Do you have records for the amount of Sargassum hauled? |
| ☐ Yes<br>☐ No |
| 2.5 If yes, can you share those records? |
| ☐ Yes<br>☐ No |
| 2.6 Where is the Sargassum taken? |
| 2.7 How much does it cost to haul the Sargassum? |
| 2.8 What would happen if your agency did not remove the Sargassum when in excess at the beach? |
| 2.9 What are the consequences you believe for inaction? |

3. **Experiences with composting**

| |
|---|
| 3.1 Is there a specific department that oversees the maintenance of the Sargassum pile? |
| ☐ Yes<br>☐ No |
| 3.2 If yes, what is the department name? |
| 3.3 Does your agency facilitate composting of Sargassum? |
| ☐ Yes (Proceed with the following questions below)<br>☐ No |
| 3.4 If no, what are the barriers to initiating a composting program? |

If yes, proceed with the following questions.

| |
|---|
| 3.5 How would you describe your experience with composting? |
| 3.6 What went well? |
| 3.7 What aspects were challenging? |
| 3.8 If you had to start all over what would you do differently? |
| 3.9 Is there special permitting that is needed to run this Sargassum composting facility? |
| ☐ Yes<br>☐ No |
| 3.10 If yes, what are the permits that are required? |
| 3.11 Are they from the state, county or both? |
| ☐ State<br>☐ County<br>☐ Both |
| 3.12 What are the specific permits that are required, if any? |
| 3.13 What is the compost used for? |
| 3.14 Is there a notable difference in the quality from other compost products that were traditionally used? |
| ☐ Yes<br>☐ No |
| 3.15 If yes, what are some of those differences? |

4. **Costs**

| |
|---|
| 4.1 Do you have a budget for maintaining the beaches? |
| ☐ Yes<br>☐ No |
| 4.2 Can you share that information? |
| ☐ Yes<br>☐ No |

4.3 How much was spent on machinery used?

| Machine | Cost to operate | Cost to maintain | Time spent in operation |
|---|---|---|---|
| Barber Surf Rake | | | |
| Tractor to pull surf rake | | | |
| 8 yd truck | | | |
| | | | |
| | | | |
| | | | |
| | | | |

4.4 How much is spent on labor?

| Position | Description of position | Salary (yearly, hourly) | Time spent on task |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

4.5 Is there an estimate on the cost of the space that is used for the composting site? (i.e. Synder Park)

☐ Yes

☐ No

4.6 If yes, how much?

4.7 Is the compost used throughout the city for other purposes?

☐ Yes

☐ No

4.8 If yes, how much is saved?

4.9 Would you be available to provide information on any follow up questions on costs and other factors in creating the budget?

☐ Yes

☐ No

## 5. Expectations

| 5.1 Do you feel like the city supports the program? |
|---|
| ☐ Yes<br>☐ No |
| 5.2 How so? |
| 5.3 What do you expect the project to look like in the next five years? |
| 5.4 Would you recommend other local government's adopting this strategy to dispose of Sargassum? |
| ☐ Yes<br>☐ No |
| 5.5 Why or why not? |

## 6. Questions for municipalities

| 6.1 Has there been an increase in the amount of Sargassum that has made its way on shore? |
|---|
| ☐ Yes<br>☐ No |
| 6.2 How much of an increase have you noticed? |
| 6.3 How much does the City spend on dealing with the Sargassum issue? |
| 6.4 Would the City be interested looking other alternatives to deal with the Sargassum influxes other than hauling away or integrating into the sand? |

## 7. Questions for Companies

| 7.1 Have you invested in other alternatives to the sargassum collected? |
|---|

## 8. Conclusion

| 8.1 Do you have any questions for us? |
|---|

## Questionnaire sent out to Potential Compost Users

| | |
|---|---|
| 1. | How long have you been in operation? |
| 2. | Do you make your own compost or buy compost? |
| 3. | If you make compost, how do you make it and what type of compost is it? |
| 4. | Do you sell the compost that you create? If so, how much do you charge? |
| 5. | What is the composition of the compost that you either buy or make? |
| 6. | What plants is the compost applied to? |
| 7. | Is there a specific season that the compost is applied? |
| 8. | Do you know about seaweed fertilizer or have heard anything about the product? Do you have an interest in such a product? |

# Appendix B

# Production and Properties of Compost

## Sargassum collection and composting process

The composting process consisted of small- and large- scale efforts. *Sargassum* collection for the first small-scale effort consisted of collecting 72 kg on October 15, 2020. *Sargassum* collection for the second larger effort consisted of using a 6.1 $m^3$ dump truck on May 24, 2021. In both efforts, the *Sargassum* was collected using a mechanical beach cleaner (Barker® Surf Rake). A total of six conditions were evaluated for *Sargassum* compost. Four were evaluated at the small scale (tumbler style composters). Using tumbler composters, the four conditions evaluated were unwashed *Sargassum*, washed *Sargassum*, adding grass clippings (therein after called grass), and adding mulch (therein after called mulch)). The washed *Sargassum* was included due to original concerns about the possibility of excessive salt in the compost product. Grass clippings and mulch were chosen as they tend to be readily available locally. The remaining two conditions consisted of large-scale piles, one with unwashed *Sargassum* outdoors (hereafter called unwashed outdoors) and the other mixed with vegetative waste collected from within a city (hereafter referred to as vegetative waste outdoors)). Again, vegetative waste was chosen because community stakeholders identified it as being one of the readily available feedstock materials given programs designed to segregate its disposal.

Within the small-scale effort, the collected *Sargassum* was evenly distributed into four piles (18 kg each). Two tumblers (EJWOX® Dual Tumbler Composter) each with two chambers were used. The tumblers were made of plastic, and all interior metal components including screws and dowels were covered and replaced with plastic components to minimize any metal contact with *Sargassum* during the experiment. Leaching test of the plastic material used showed that metals released were below method detection limits. For the large-scale experiments, the collected *Sargassum* was evenly distributed into 2 piles located in southern Florida USA within an outdoor storage property (GPS coordinates: 25.988944, -80.156028)

Compost from each experiment was turned once every two weeks to promote decomposition. The small-scale piles were turned using the handle on tumbler composters, while turning of the large scale piles utilized a small front end loader (Catepillar ®). At 140 days, samples from both experiments were collected using a pair of plastic tongs and placed in clean Whirl-Pak™ bags. Once collected, the samples were placed in a cooler with ice packs and transported back to the laboratory. In the laboratory, samples were mixed further and divided into four parts (metals, microbes, bulk physical-chemical parameters, and nutrients) and placed in Whirl-Pak™ bags.

## Elemental Analyses

Elemental analyses by triple quadrupole ICP-MS (Agilent 8900 ICP-QQQ) were conducted in MS/MS mode at the Rosenstiel School of Marine, Atmospheric, and Earth Science at the University of Miami. Samples analyzed by ICP-QQQ-MS were washed with 18MΩ MilliQ water, freeze dried, and digested using ultra trace hydrogen peroxide and nitric acids in 30 mL teflon vessel on a hotplate. Accuracy of the analysis and digestion method using the ICP-QQQ was assessed using internal standards and four Certified Reference Materials (CRM). Further information about calibration and quality control measures can be found in the supplemental text.

**Bulk physical-chemical parameters and nutrients measurements to assess potential for plant growth)**

In addition to major ions that are used to assess nutrients available for plant growth as described in the elemental analyses section above, samples were also analyzed for bulk physical-chemical parameter and additional nutrients (nitrogen and carbon). Bulk physical-chemical parameters included temperature, moisture content, pH, and conductivity. Temperature was measured by inserting a thermometer into each pile (glass thermometer, VWR; compost thermometer, Reotemp) about 7.6 cm into each pile. For moisture content, one aliquot of the compost sample was gravimetrically analyzed (dried in an oven set at 40 ºC for 24 hours). Standard methods (SW-846 Test Method 9045D) were adapted for the measurement of pH and conductivity.

The additional nutrient measures of nitrogen and carbon, plus their ratios (C:N ratios) were measured using an elemental analyzer (Costech ECS 4010 CHNSO) at the Stable Isotope Laboratory (SIL) at the University of Miami, RSMAES campus. Samples were washed with de-ionized water and placed in an oven to dry at 40 °C for about 24-48 hours. Once dried, samples were homogenized and placed in an acid washed glass vial for later analysis. The general principles of analysis included combusting at 1100 ˚C a weighed quantity (1.5 to about 2.0 mg of dried sample). After removal of water from the resulting gas, it was then passed through an capillary which separates the evolved $CO_2$ and $N_2$ gases. After separation, the gases were transferred to an isotope ratio mass spectrometer (Thermo Scientific Delta V Advantage). Quantification in units of mg was based upon a calibration curve of peak areas measured by the instrument using standards of known C and N compositions (glycine and acetanilide). The weights of the standards were chosen to bracket the expected range of organic carbon and nitrogen in the samples. The molar C:N ratio was computed from the measured carbon to measured nitrogen, by weight.

# Appendix C

## Signs used about *Sargassum* to educate the public

**Photos of Signage used by Agencies**

A)


B)


Figure C.1: Signage that is used around the beach by the various beach mangers. This is an example of the information that is presented to beach goers.