Evaluating Compost as a Means to Recycle *Sargassum* Macroalgae (Seaweed)

(FINAL)

Submitted March 31, 2022

Authors

Afeefa Abdool-Ghany, M.S.[1]
Helena Solo-Gabriele, Ph.D., P.E.[1]
Peter Swart, Ph.D.[2]
Amanda Oehlert, Ph.D.[2]
Trent Blare, Ph.D.[3]

[1]University of Miami, College of Engineering, Coral Gables, FL
Department of Chemical, Environmental, and Materials Engineering

[2]University of Miami, Rosenstiel School of Marine and Atmospheric Sciences
Department of Marine Geosciences

[3]University of Florida
Tropical Research and Education Center, Homestead, FL

Hinkley Center for Solid and Hazardous Waste Management
University of Florida
P. O. Box 116016
Gainesville, FL 32611
www.hinkleycenter.org

This page left intentionally blank

PROJECT TITLE: Evaluating Compost as a Means to Recycle Sargassum Macroalgae (Seaweed)

PRINCIPAL INVESTIGATOR: Dr. Helena Solo-Gabriele
AFFILIATION: University of Miami, Dept. of Chemical, Environmental, and Materials Engineering
CONTACT INFORMATION: hmsolo@miami.edu, 305-284-3467

CO-PRINCIPAL INVESTIGATOR: Dr. Peter Swart
AFFILIATION: University of Miami, Dept. of Marine Geosciences - Rosenstiel School of Marine and Atmospheric Science
CONTACT INFORMATION: pswart@rsmas.miami.edu, 305-421-4103

CO-PRINCIPAL INVESTIGATOR: Dr. Amanda Oehlert
AFFILIATION: University of Miami, Dept. of Marine Geosciences - Rosenstiel School of Marine and Atmospheric Science
CONTACT INFORMATION: aoehlert@rsmas.miami.edu, 305-421-4405

CO-PRINCIPAL INVESTIGATOR: Dr. Trent Blare
AFFILIATION: University of Florida Tropical Research and Education Center, Homestead, FL
CONTACT INFORMATION: tblare@ufl.edu, 786-217-9248

LEAD GRADUATE STUDENT: Afeefa Abdool-Ghany
AFFILIATION: University of Miami, Dept. of Chemical, Environmental, and Materials Engineering
CONTACT INFORMATION: aaa625@miami.edu, 954-298-4073

PROJECT WEB-SITE: https://hmsolo.miami.edu/?page_id=722

PROJECT DURATION: September 1, 2020 to March 31, 2022

ABSTRACT: *Sargassum* spp. is one of the dominant forms of marine macroalgae (seaweed) found at beaches throughout Florida. 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 as much as $35 to $45 million a year per Florida coastal county. Once in the landfill, the seaweed decays and can contribute towards the release of hydrogen sulfide. Coastal counties are looking for alternative ways to handle the material once removed from the beach. Composting offers one potential alternative. One limitation of seaweed compost is its potential to contain excess salts which can be detrimental to plant growth. The objective of this study was to evaluate the suitability of producing compost from seaweed. The project was divided into two phases. The first phase involved two tumbler composters with four compartments (washed, unwashed, unwashed mixed with green yard waste, and unwashed mixed with woody yard waste). The second phase, in collaboration with the City of Hallandale Beach, involved two larger scale compost piles with different washing methods (washed versus unwashed seaweed). The compost produced from each of these phases was analyzed for bulk physical-chemical properties (including salinity), nutrients (including carbon, nitrogen, and phosphorus), metals, and bacteria. Results show that the bulk physical and chemical parameters for phase I and phase II were not within the standards outlined by the U.S Composting Council (USCC). Nutrients such as the C:N ratios were not within the ranges outlined by the USCC as well. When other waste streams (brown clippings) were added to the *Sargassum* for decomposition, the C:N ratios increased. This observation was noted in both phases of the project with the addition of mulch in phase I and the addition of vegetative waste in phase II. Metals were of concern especially when evaluating valorization options. Arsenic was detected in both phases, but was lower than two of the three regulatory standards outlined. Finally, the abundance of bacteria was not within the standards of the USCC for phase I but was for phase II. Even though certain USCC standards were not met, a useable product was still created in terms of metals, bacteria (phase II), and plant growth. USCC standards are based on the different materials, while there are no specific standards for *Sargassum*. Results thus highlight that *Sargassum* can be diverted from landfill disposal and used to make compost. We recommend the development of specific standards for compost made from seaweed.

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

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

Student Researcher:
Full Name: Afeefa Abdool-Ghany
Email: aaa625@miami.edu
Anticipated Degree: PhD. in Chemical, Environmental, and Materials Engineering (Environmental Emphasis)
Department: Department of Chemical, Environmental, and Materials Engineering, University of Miami, Coral Gables, FL

Metrics:

1. Research publications from THIS Hinkley Center Project.
   JOURNAL ARTICLES
   - In Progress

   ABSTRACTS
   - 2021 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 is able to 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:

- "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?
   - Upon initiation of this project, we have been in contact with the City of Fort Lauderdale. Mark Almy and his team have been gracious to show us their composting operations. The composting facility was visited on September 16, 2020.
   - One of our TAG members (Chip Jones) has allowed us to tour his facilities and see the machines that are used in beach grooming operations. We met with him and took a tour of his operations on December 11, 2020.
   - Another TAG member (Mark Richards) offered for us to tour Crandon Beach to get an idea of the influx of seaweed that plagues the unique area. We toured Crandon Beach with Mark Richards on December 29, 2020.
   - We are in contact with Dr. Kimberly Moore, from the University of Florida, IFAS. She has provided guidance on the quality of compost and helped to design the radish bioassay experiments. We are working with her to establish a set of standards that can exclusively be used for *Sargassum* compost.

- Afeefa works in Dr. Amanda Oehlert's lab to analyze the metals and phosphorous found in the tumbler composters as well as the compost piles.
- Dr. Peter Swart invited us to be a part of the proposals submitted to Commissioner Regalado. We also analyze for nutrients in his lab.
- 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.
- 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.
- Ana Zangroniz who is a Florida Sea Grant Extension Agent at the UF/IFAS Extension Miami-Dade County, reached out to us requesting that we present our research to Miami-Dade County. From this presentation we also were in contact with Tom Morgan, who is the Chief of Operations for Miami-Dade County Parks, Recreation and Open Spaces Dept.
- Rebecca Wakefield who is the Chief of Staff in the office of Commissioner Raquel Regalado, reached out to us to find out more about our research. She has indicated an interest in developing a coalition to address the seaweed disposal issue.

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 considering classifying Sargassum compost as yard trash. 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 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 Hallandale Beach for their support in this project and for allowing us to conduct part of this study onsite.
- 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

Name	Affiliation and Address
Helena Solo-Gabriele	Professor, Principal Investigator University of Miami, 1251 Memorial Drive McArthur Bldg R 252, Coral Gables, FL 33146
Peter Swart	Professor, Co-Principal Investigator University of Miami, Dept. of Marine Geosciences - Rosenstiel School of Marine and Atmospheric Science, Miami, FL, 33149
Amanda Oehlert	Assistant Professor, Co-Principal Investigator University of Miami, Dept. of Marine Geosciences - Rosenstiel School of Marine and Atmospheric Science, Miami, FL, 33149
Afeefa Abdool-Ghany	Graduate PhD Student University of Miami

HINKLEY CENTER

Name	Affiliation and Address
John Schert	Director University of Florida, Gainesville, FL
Ana Pak	Media Specialist University of Florida, Gainesville, FL

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 University of Florida, IFAS|Fort Lauderdale Research and Education Center
Ligia Collado-Vides	Senior Lecturer; Associate Chair Department of Biological Sciences, Florida International University
Dan Meeroff	Professor and Associate Chair Department of Civil, Environmental & Geomatics Engineering, Florida Atlantic University
Ana Zangroniz	Florida Sea Grant Extension Agent UF/IFAS Extension Miami-Dade County
Shelly Krueger	Florida Sea Grant Agent II University of Florida IFAS Extension, Monroe County
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 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 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 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
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 Florida Department of Health in Miami-Dade County
Karen Moore	Environmental Administrator-FDEP Division of Waste Management
Lauren O'Connor	Government Operations Consultant-FDEP Division of Waste Management
Chris Perry	FDEP Division of Waste Management

TAG MEETING PARTICIPANTS. Note: Participation in the TAG meetings does not imply an endorsement of the research.

Name	Affiliation
MEETING 1 (Online)	
Afeefa Abdool-Ghany	University of Miami
Alejandro Quintás	NEAT Sand
Alyssa Jones-Wood	City of Hallandale Beach
Amanda Oehlert	University of Miami-RSMAS
Cathie Schanz	City of Hallandale Beach
Chip Jones	Beach Raker
Chris Snow	Consolidated Resource Recovery, Inc.
Christopher Perry	Florida Department of Environmental Protection
Daniel Meeroff	Florida Atlantic University
David Hill	Recycle Today Florida
Emilio Lopez	SOP Technologies
Helena Solo-Gabriele	University of Miami
John Schert	Hinkley Center for Solid and Hazardous Waste Management
Josefina Olascoaga	University of Miami -RSMAS
Karen Moore	Florida Department of Environmental Protection
Katarzyna Kulpa	Village of Key Biscayne
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
Peter Swart	University of Miami-RSMAS
Samir Elmir	Florida Department of Health in Miami-Dade County
Tony Brown	Broward County Solid Waste and Recycling Division
Valentina Caccia	Division of Environmental Resource Management (DERM)

TAG MEETING PARTICIPANTS. (Cont'd) Note: Participation in the TAG meetings does not imply an endorsement of the research.	
Name	**Affiliation**
MEETING 2 (Online)	
Afeefa Abdool-Ghany	University of Miami
Amanda Oehlert	University of Miami-RSMAS
Amede Dimonnay	Broward Engineering and Permitting Division
Ana Pak	Hinkley Center for Solid and Hazardous Waste Management
Ana Zangroniz	Florida Sea Grant Extension Agent for Miami Dade-County
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)
El Kromhout	Florida Department of Environmental Protection
Helena Solo-Gabriele	University of Miami
John Schert	Hinkley Center for Solid and Hazardous Waste Management
Kimberly Moore	University of Florida, IFAS
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
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.	
Name	**Affiliation**
MEETING 3 (Online)	
Abby Crombie	Georgia Institute of Technology
Afeefa Abdool-Ghany	University of Miami
Alejandro Quintás	NEAT Sand
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

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

C:N	Carbon to Nitrogen ratio
CRM	Certified Reference Materials
FDEP	Florida Department of Environmental Protection
HCSHWM	Hinkley Center for Solid and Hazardous Waste Management
ICP-AES	Inductively coupled plasma-atomic emission spectrometry
ICP-QQQ-MS	Inductively coupled plasma triple quadrupole mass spectrometry
ND	None Detected
PI	Principal Investigator
RFP	Request for Proposal
RSMAS	Rosenstiel School of Marine and Atmospheric Science
SCLT	Soil Cleanup Target Levels
SIL	Stable Isotope Laboratory
UM	University of Miami
USCC	United States Composting Council
US EPA	United States Environmental Protection Agency
XRF	X-ray fluorescence

UNITS OF MEASURE

$	Dollars
%	Parts per hundred
ºC	Degrees Celsius
CFU/100mL	Colony forming units per one hundred milliliters
kg	Kilograms
L	Liter
mg	Milligrams
m^3	Cubic meters
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 (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 objective of this project was to determine whether composting represents a feasible alternative to managing *Sargassum*. Specifically, through the current study we assessed the characteristics of the compost [physical-chemical parameters (temperature, moisture content, pH, and conductivity), nutrient ratios (C:N, P), elemental concentrations, bacteria levels, and ability to sustain plant growth] in a small scale (phase I) and larger scale (phase II) setting. The first phase involved experiments using two tumbler composters with four compartments (washed, unwashed, unwashed mixed with grass clippings, and unwashed mixed with mulch or brown clippings). The second phase involved two larger scale compost piles one with a compost additive (a control pile and vegetative waste).

Results show that *Sargassum* decomposes to produce a soil-like product capable of plant growth. However, not all physical-chemical parameters were within standards outlined by the U.S. Composting Council (USCC). Moisture content and conductivity were lower than the standards outlined by USCC, while pH was slightly higher. Nutrient concentrations/ratios for both small and large scale experiments were also not within the standards outlined by the USCC. Within the small scale experiment, the grass clippings treatment had the lowest C:N ratios while the mulch treatment had the highest. Within the large scale experiments, the *Sargassum* treatment had low C:N ratios compared to the *Sargassum* and vegetive waste treatment. Interestingly for the metals analysis, arsenic was within three of the four standards that were used for comparison. Four standards were chosen for comparison since Florida does not measure arsenic in compost samples. Finally for the bacteria, enterococci and fecal coliform, levels were not within the range outlined by US EPA for the small scale experiments. For the large scale experiments, the bacteria levels were within the acceptable range. The compost produced from the experimental tumblers was then used to grow radish seeds (*Raphanus sativus L., var. Champion*). Different proportions of the compost were mixed with a control product to evaluate the efficiency of the compost. Overall, the compost was able to produce radish seedlings.

In summary, even though the compost quality did not meet all the standards outlined by the USCC, the compost was still considered useable based on the levels of bacteria, metals, and ability to grow plants. It provides an alternative to landfilling. 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 the waste management.

CHAPTER I

MOTIVATION, OBJECTIVES, & 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). There are two known sources of *Sargassum*, the Sargasso Sea in the North Atlantic and the newer source region called the Great Atlantic Sargassum Belt (GASB) (Wang et al., 2019). The growth of the large mats of Sargassum are believed to be fueled by the global flow of nutrients with some studies pointing to the release of nutrients from the deforestation of the Amazon rain forest as one potential cause for the sudden increase in *Sargassum* within the Caribbean (Wang et al.,2019). Within these two regions *Sargassum* persists and proliferates, and portions are transported towards the coastlines where they strand onshore. 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. Once in the landfill, the seaweed begins to rot and can release hydrogen sulfide. Coastal counties are looking for alternative ways to handle the material once removed from the beach. Composting offers one potential alternative.

The goal of this study is to evaluate the feasibility and quality of composting *Sargassum* in both a small and large scale setting. The objectives of this project are to evaluate compost as a means of reusing *Sargassum*, thereby limiting the burden on landfills. Two phases have been outlined to achieve this goal. Phase I (Tumbler Composters) will focus on evaluating additives on the physical-chemical parameters of the resulting compost. Samples from Phase I will be analyzed for bulk physical chemical parameters, nutrients, elemental composition, and bacteria. Phase II (Compost Piles) will be conducted at a larger scale and will focus on a control pile of *Sargassum* compared to *Sargassum* and vegetive waste. The compost piles of Phase II will be analyzed for the same parameters as for Phase I. The experimental study site for Phase I will be at the UM RSMAS Campus. The experimental study site for Phase II will be within the City of Hallandale Beach.

I.2 Background

I.2.1 Shoreline Accumulations of Sargassum

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. The growth of the large mats of *Sargassum* are believed to be fueled by the global flow of nutrients with some pointing to the release of nutrients from the deforestation of the Amazon rain forest as one cause for the sudden increase in *Sargassum* within the Caribbean (Wang et al., 2019). Additionally, it is believed that the amount of *Sargassum* produced by the oceans will increase as the temperature begins to rise (Huffard et al., 2014).

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 (Atkin, 2018). In the water, the *Sargassum* mat can become anoxic and block light to nearshore seagrass beds resulting in seagrass die off, further fueling anoxic conditions (Atkin, 2018). 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 (Sargassum: A Resource Guide for the Caribbean, 2015). When left on the shore to decompose, *Sargassum* will release unpleasant odors (hydrogen sulfide; Atkin, 2018; Langin, 2018) into the environment. It also attracts insects, *e.g.* sand flies, as it decomposes (Swinscoe et al., 2018). Bacteria levels in the seaweed also tend to increase (data from separate study by the project investigators). When the decomposing *Sargassum* is washed back to the water it results in the issuance of beach swim advisories due to elevated bacteria levels (Swinscoe et al., 2018) further impacting the economy of the area by limiting access to safe recreational waters along the coast.

Alternative methods are needed for handling excessive amounts of *Sargassum* that are found on Florida's coastlines. To combat this problem, local government agencies are exploring how to remove the seaweed and are looking for beneficial uses. One beneficial use is compost. 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 (Sembera et. al., 2018). 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.

I.2.2 Measurement Parameters for Compost

Measurement parameters can be separated into four broad categories. They include bulk physical-chemical parameters (electrical conductivity, pH, moisture content and temperature), nutrients (carbon, nitrogen, carbon to nitrogen ratios and phosphorus), elemental composition (including major ions, metalloids such as arsenic, and heavy metals), and bacteria (specifically the fecal indicator bacteria used to issue beach swim advisories, enterococci. Fecal coliform, which is the target microbe of the U.S EPA biosolids regulations, should also be monitored).

Bulk physical-chemical parameters: Compost made from seaweed, because it originates from the ocean, may result in high levels of soluble salts. **Electrical conductivity (EC)**, reported in units of mS/cm or μS/cm is an indirect measure of these salts. When the concentration of sodium is high in compost it can be detrimental to plants. It can interfere with the root uptake of water (Gondek et al., 2019). Domesticated plants can be divided into two salinity thresholds: salt-sensitive with tolerances of 1 to 3 mS/cm and moderately salt tolerant plants with tolerances of 5 to 10 mS/cm ("Listing of Halophytes & Salt-Tolerant Plants.", 2020).

pH should also be measured during composting because it allows for the monitoring of the decomposition process. The microorganisms that promote the compost process thrive best under neutral to acidic conditions, within a pH range of 5.5-9.0 ("Monitoring Compost pH.", 1996). Acidic conditions are favorable for the growth of fungi. Mature compost has a pH of around 6-8.

Another property that should be measured throughout the process of composting is **moisture content**. Moisture content is the ratio of the weight of water to the weight of solids. Ideally the moisture content of the compost should be between 40%-60% ("Compost Needs-Moisture", n.d). High moisture content should be avoided because it can cause anerobic conditions. Low moisture content does not provide enough water for microorganisms to metabolize the *Sargassum*. Aeration is also very important, as it is helpful in reducing the high moisture content of *Sargassum* compost. In order to achieve aeration, turning the material is the most common method. Frequency of turning the piles depends on the moisture content and the type of material. Materials that have a high moisture content reduce the pore space for air to be introduced in the pile. Also, if a compost material has a high C:N ratio then aeration through turning may not be needed as often as low C:N ratio material ("Compost Needs-Aeration.", n.d). Moisture content is also related to the water-holding capacity of compost. The water-holding capacity is the ability to physically hold water against the force of gravity and moisture content is a part of this formula.

Temperature is another parameter that controls the production of compost. Heat is released during the compost process. High temperatures are important for the destruction of pathogenic organisms. The optimum temperature range is 135° - 160° Fahrenheit (Richard, 2000). High nitrogen materials, such as grass clippings and *Sargassum*, result in the production of excess heat. In the beginning the compost will exhibit high temperatures and then gradually drop. By monitoring the temperature regularly, a researcher can monitor the speed of the composting process. The temperature can be controlled through proper mixing or turning of the pile where the center tends to have higher temperatures and the outer edges tend to have lower temperatures due to increased aeration ("Compost Needs-Aeration.", n.d).

General recommendations for bulk physical and chemical properties in plant growing substrates are given by Klock-Moore and Fitzpatrick (1999) and can be found in Table I.1.

Table I.1:Recommendations for Physical and Chemical Properties (from Klock-Morre and Fitzpatrick, 1999)

Parameter	Bedding Plants	Foliage Plants	Woody Ornamentals
Electrical Conductivity (mS/cm)	0.75-3.49	0.57-1.43	0.50-1.00
pH	5.8-6.2	5.5-6.5	5.8-6.2
Water-holding Capacity (%)	N/A	20-60	35-50

N/A-no values were available

Nutrients: Among the nutrient measurements, **Carbon to nitrogen (C:N) ratios** are the most important for microbial decomposition ("Composting Chemistry", 1996). Carbon is an energy source and is the basic building block of microbial cells and nitrogen is necessary for cell growth and function. Optimum carbon to nitrogen ratios for compost in the beginning stage of composting is between 25:1 and 30:1 (Christopher and Asher, 1994). To adjust C:N, additives can be added to compost. Materials that are green and moist are generally high in nitrogen and those that are brown are generally high in carbon. Carbon to nitrogen ratios have been reported as 27:1 for *Sargassum* in coastal waters (LaPointe et. al., 2014), 55:1 for green clippings (Christopher and Asher, 1994), and 560:1 for wood chips (Christopher and Asher, 1994). The C:N ratio of *Sargassum* compost can be adjusted using either one of these additives, with wood chips more strongly increasing the proportion of carbon relative to green clippings.

Phosphorus is also an important major nutrient or macronutrient used by plants. It is important for root development and encourages rapid root growth, improves flower and seed development, and hastens maturity in food crops (Alexander, 2016). Lapointe (2014) has identified the C:P for coastal *Sargassum* in the range of 268-271:1. An excess of phosphate is considered a pollutant in water so these levels should be measured.

Metals: Sembera et al. 2018 evaluated the concentration of **metals** in *Sargassum* collected from beaches in Texas. Results are provided in Table I.2 where they are compared to regulatory standard levels. This comparison indicates that among the metals, arsenic exceeds the residential SCTL and may be a concern if the compost is used in residential applications. Specifically, Sembera et al. measured arsenic in seaweed in the 4.2 to 4.4 mg/kg range whereas residential guideline SCTL levels are set at 2.1 mg/kg. The other metals found in Table I.2 do not exceed the residential SCTL guidelines. These metals are well below the limits of the U.S. EPA as well.

Table I.2: Metal Concentrations in Sargassum Relative to Regulatory Guidelines

Pollutant	USCC	U.S. EPA	FDEP-Criteria for the use of compost	FDEP-Direct Exposure		Sembera et al. (2018)	
	Must meet the EPA testing limits for heavy metals (mg/kg)	Ceiling Concentration Limits for all biosolids applied to land (mg/kg)	The total amount of heavy metal applied to soils shall be (in pounds per acre)	Residential (mg/kg)	Commercial / Industrial (mg/kg)	Washed *Sargassum* (as is basis) (mg/kg)	Unwashed *Sargassum* (as is basis) (mg/kg)
Arsenic	41	75	*	**2.1**	12	**4.2**	**4.4**
Cadmium	39	85	4.45	82	1,700	<0.3	<0.3
Chromium	*	3,000	*	210	470	NM	NM
Copper	1,500	4,300	111	150	89,000	10.7	10.3
Lead	300	840	445	400	1,400	3.8	4.9
Mercury	17	57	*	3	17	0.009	0.012
Molybdenum	*	75	*	440	11,000	<0.8	<1.0
Nickel	420	420	111	340	35,000	5.4	4.9
Selenium	100	100	*	440	11,000	<0.8	<1.0
Zinc	2,800	7,500	222	26,000	630,000	35.2	38.5

*Not regulated
NM- Not measured

<u>Bacteria</u>: In terms of **bacteria**, studies have shown that beach water and sand quality degrade when the fecal indicator bacteria levels (specifically enterococci) exceed 100 colony forming units (CFU) per gram within the *Sargassum*. In our prior work, we have observed that enterococci levels increase as the *Sargassum* decomposes, reaching levels greater than 1000 CFU/g. The water content of the decomposing *Sargassum* is lower than the water content for fresh *Sargassum*. This may also play a role in the number of bacteria that is found in the *Sargassum*. These excessive levels of enterococci in the *Sargassum* contribute to beach water quality advisories as the *Sargassum* is left on the shoreline to decompose.

<u>USCC:</u> The gold standard of compost products is outlined by the USCC. For most of the parameters mentioned before, the USCC has standards of their own. The table (Table I.3) below summarizes the standards of the USCC in terms of the concentration of metals, the USCC states that U.S. EPA testing limits for heavy metals must be met. Pathogens levels outlined by the U.S. EPA must also be met.

Table I.3: Standards outlined by the USCC

Parameter (units)	USCC Range
pH	5.0-8.5
Soluble Salts (mmho/cm)	1-10
Solids (%)	50-60
Moisture (%)	40-60
Total nitrogen (%)	0.5-2.5
Carbon (%)	<54
C:N	<20

I.2.3 Seaweed Management in Florida

Seaweed stranding events can cause economic hardships for counties and cities located along the coast. In Florida, tourism is very important to the economy and having a beach with excessive seaweed hurts the tourism industry. In Mexico tourism dropped approximately 30-35% because of seaweed strandings ("Tourism down 30-35% Due to Sargassum: Playa Del Carmen Mayor-Elect." , 2018). Beaches across Florida manage seaweed differently. Some cities leave it on the sand (Figure I.1a and I.1b), some may integrate the seaweed into the sand creating an organic edge in the sand (Figure I.1c). Others may use front end loaders to remove it and then use trucks to send it off to a landfill.

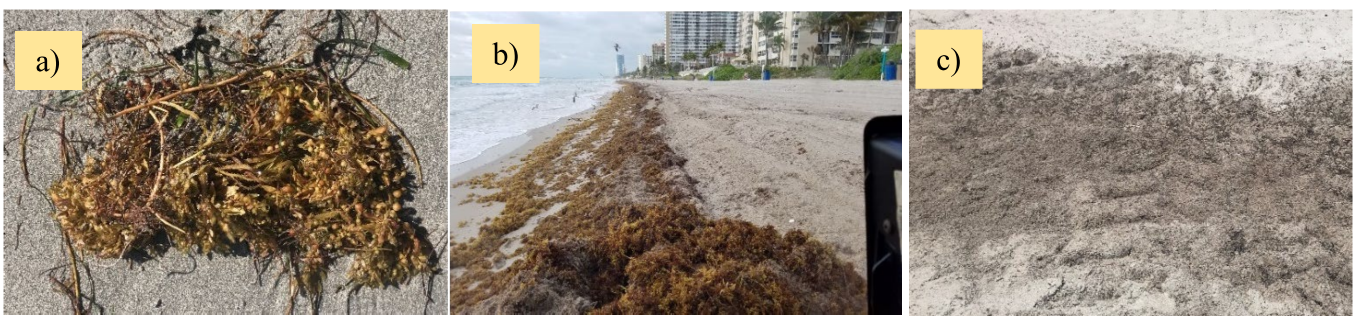

Figure I.1: a) Sargassum found on the beach. b) Beach with Sargassum c) Integrated sand and seaweed.

For this study we will focus on *Sargassum* as opposed to seaweed, as it is more well defined and is also the dominant species associated with the overwhelming large-scale strandings.

CHAPTER II

QUALITY OF SARGASSUM COMPOST

CHAPTER II

QUALITY OF SARGASSUM COMPOST

II.1 Introduction

The first wave of massive rafts of *Sargassum* that washed onshore in the Caribbean was documented in 2011 (Langin, 2018; Davis et al., 2020). The year 2018 saw a record breaking quantity of *Sargassum* reaching the shores of the Caribbean alone, with 200 million metric tonnes measured in June (USF Outlook Bulletin, 2018). In 2021 an estimated 5.1 and 4.6 million tonnes of *Sargassum* were observed in the tropical Atlantic in January and February respectively, which doubled in March to 10.1 million metric tonnes (USF Outlook Bulletin, 2021). It has become generally accepted that strandings across the Caribbean and U.S. coastal communities are now part of a “new normal.”

Once onshore, the strandings, when excessive, threaten the coastal environment because it begins to decompose and rot when unmanaged. The decomposing process removes oxygen from the surrounding water, thus killing fish and other marine life (Cruz-Rivera et al., 2015). In the water the *Sargassum* can become anoxic and blocks light to nearshore seagrass beds resulting in seagrass die off which fuels further anoxic conditions. Not only does marine life become affected, but human health is also at risk. Toxic gases, such as hydrogen sulfide and ammonia are produced as the *Sargassum* begins to decompose (Resiere et al., 2018). Exposure to these toxic gases can cause pulmonary, neurological, and cardiovascular lesions.

As a result of these negative ecologic and human health impacts, *Sargassum* stranding events are causing economic loses through decreases in fishing and tourism industries throughout the Caribbean as well as U.S coastal cities. In Florida and throughout the Caribbean, tourism is very important to the local economies and having a beach with excessive seaweed degrades the aesthetic quality of the area. Clean up costs associated with *Sargassum* strandings have been estimated to reach up $120 million for the year 2018 in the Caribbean alone (Caribbean Regional Fisheries Mechanism, 2018).

Beaches across Florida manage seaweed differently and are maintained by various organizations including federal and state agencies, cities, counties, and private owners. Some entities leave stranded *Sargassum* on the sand which is of minor impact when normal amounts wash onshore. When the quantities are excessive, some beach managers may integrate the seaweed into the sand creating an organic edge in the sand. Others may use front end loaders to remove it and then use trucks to transport it to a landfill. Hauling to landfills is most common when strandings are especially large. Costs associated with landfilling are high, and disposal of *Sargassum* in landfills can also be viewed as a waste of a potentially renewable resource.

Thus, there is an urgent need to develop sustainable approaches to manage *Sargassum* during massive strandings. Composting can be an alternative management method which makes use of this potentially valuable resource. However, few studies are available that document the properties of *Sargassum* compost. For example, the U.S Composting Council (USCC) has developed guidelines for compost and few data are available to assess whether *Sargassum* compost meets USCC guidelines which includes limits on the concentration of heavy metals, as well as microbes. One of the few studies that have evaluated the composition of *Sargassum* compost (Sembera et al. 2018) established that composting of *Sargassum* is possible and washing of the material does not make a difference during the composting process. Sembera et al. (2018) found that final compost products were within the compost quality standards outlined by the USCC. In the Sembera et al. study, each compost pile had 48% food waste, 48% wood chips, and 4% *Sargassum*. In another study by Walsh and Waliczek (2020), four mixes were assessed with either 25% or 41.5% *Sargassum* along with various proportions of food or fish waste and wood chips. It was found that all four protocols yielded final products within the USCC standards. The best protocol was equal parts *Sargassum* and wood chips (41.5%), food waste (13%), and fish waste (4%).

Although these prior studies provide valuable information concerning the composting of *Sargassum*, these studies were missing a control pile of pure (100%) *Sargassum* as well as measurements of microbes (e.g., analyses of enterococci and fecal coliform). Currently there are no known standards or benchmarks for compost quality made of *Sargassum*. The objective of the current study is to fill this knowledge gap by describing the quality of compost made from *Sargassum* within a small and large scale effort, and to provide information on the economics of establishing a *Sargassum* composting operation. This study evaluated physical-chemical parameters (temperature, moisture content, pH, and conductivity), nutrient ratios (C:N, P), elemental composition (including heavy metals), and bacteria levels. The ability of *Sargassum* compost to support plant growth was evaluated through the cultivation of radishes.

II.2 Methods

The characteristics of *Sargassum* compost (physical-chemical properties, microbiological properties, nutrients, and elemental composition) was evaluated through two phased efforts. The first phase included four small scale (tumbler style composters) conditions (washed, unwashed, adding grass clippings, and adding mulch), while the second phase involved the creation of two larger scale (4 yd^3) piles (one with unwashed *Sargassum* and the other mixed with vegetative waste collected from within the City of Hallandale Beach). The ability of the *Sargassum* compost to support plants was evaluated by the growth of radishes *(Raphanus sativus L., var. Champion*).

II.2.1 Sargassum Collection

For the small-scale tumbler compost experiments, *Sargassum* was collected from a beach in south Florida on October 15, 2020, using a mechanical beach cleaner (Barker Surf Rake) and then transported to a composting facility in 8 yd^3 (2.3 m^3) trucks. From there it was placed on the compost pile located at Snyder Park in Fort Lauderdale. A total of about 73 kg were collected and transported back to the University of Miami, Rosenstiel School of Marine and Atmospheric Science (RSMAS) for controlled experimentation using enclosed tumbler composters. For the large scale compost piles, *Sargassum* was collected at Hallandale Beach on May 24, 2021, by a hired beach maintenance company using a mechanical beach cleaner and transported to the Department of Public Works facility of Hallandale Beach using 8 yd^3 trucks. The *Sargassum* from the 8 yd^3 truck was divided into two equal parts.

II.2.2 Composting Process

For the first phase of the characterization study, the collected *Sargassum* was evenly distributed into four piles (18 kg each). Two piles were designed to examine washing of the *Sargassum*, while the other two piles were designed to examine additives to the *Sargassum*. One pile was washed with tap water (22.71 L) to remove as much salt and sand as possible. The other pile was unwashed and would serve as the control pile. The other two piles had either grass clippings (Bermuda grass) or Cypress blend mulch (No-Float®, natural) added, respectively, to the *Sargassum* (Table II.1). The additives in each pile were well mixed by hand with the *Sargassum* before being placed in the tumbler composter. Once prepared, each pile was distributed into a compartment of a tumbler composter. Two tumblers (EJWOX® Dual Tumbler Composter) each with two chambers were used.

For the second phase of the characterization study, the collected *Sargassum* was evenly distributed into 2 piles. From Sembera et al. (2018), it was learned that washing does not make such a significant difference in the composting process as both methods produced useable products. This was confirmed from the results of the first phase of the current study. The two piles for phase two consisted of a control pile (no additives) and another with vegetative yard waste collected from within the City of Hallandale Beach.

The compost from both phases were turned once every two weeks and monitored for temperature, moisture content, pH, and conductivity. Phase I was turned using the handle on tumbler composters, while phase II utilized a small front-end loader (Caterpillar ®). Samples were also collected using a pair of plastic tongs once every two weeks for analysis of physical-chemical parameters, nutrients, elemental composition, and bacteria. Once samples were in the lab, they were well mixed and then divided into four parts (for bulk physical-chemical parameters, nutrients, metals analysis and bacterial enumeration) and placed in Whirl-Pak™ bags.

Table II.1: Treatment used for the Sargassum compost experiments with the amount of Sargassum and additives represented in kg.

Treatment	*Sargassum*	Additives
Phase I: Tumbler Composters		
Washed *Sargassum*	18 kg	-
Unwashed *Sargassum*	18 kg	-
Grass clippings + *Sargassum*	18 kg	4.5 kg
Cypress blend mulch + *Sargassum*	18 kg	1.5 kg
Phase II: Large Scale Piles		
Unwashed *Sargassum*	4 yd^3	-
Unwashed *Sargassum* + Vegetative Waste	4 yd^3	3 yd^3

II.2.3 Bulk Physical-Chemical Parameters

One portion of the sample was used to measure the bulk physical- chemical parameters. Temperature was measured by inserting a thermometer into each pile (glass thermometer, VWR; compost thermometer, Reotemp) about 7.6 cm into each pile. The temperature was recorded before and after turning the piles. 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. In brief, a sample was prepared by weighing 30 g of compost sample, then 600 mL of deionized water was added to the sample in a beaker. This mixture was then mixed for 15 minutes and allowed to settle for 5 minutes before the pH and conductivity was measured. pH (Orion Star™ A111 Benchtop pH Meter, Thermo Scientific™, calibrated against pH 4.01, 7.00, and 10.01 standards) and conductivity (EcoTestr™ CTS Pocket Conductivity, Oakton®, 1000 µS/cm at 25 °C) was measured immediately after the 5 minute settling time.

II.2.4 Nutrients Analysis

Stable C and N isotope compositions and C:N ratios were measured using an elemental analyzer (Costech ECS 4010 CHNSO and Thermo Delta V Advantage) at the Stable Isotope Laboratory (SIL) at the University of Miami, RSMAS campus. Samples were washed with E-pure water and placed in an oven to dry at 40 °C for about 24-48 hours. Once dried, samples were homogenized using a grinder and placed in an acid washed glass vial for later analysis. The general principles of analysis includes 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 isotope ratio mass spectrometer (Thermo Scientific Delta V Advantage) which provided chromatograms for C and N. Quantification in units of mg was based upon peak areas using standards of known C and N (glycine and acetanilide). The weights of the standards were chosen to bracket the expected range of organic carbon and nitrogen in the samples. The C:N was computed from the measured carbon to measured nitrogen, by weight.

II.2.5 Metals Analysis

Metals evaluated included major ions (Ca, K, Na) plus minor ions (As, Cu, Cr, Fe, Pb, Ni, Se, Zn). The minor ions are consistent with the ceiling concentrations for pollutants list specified by the U.S. Environmental Protection Agency (U.S EPA) for biosolids applied to land (U.S. EPA, 2000). Samples for metals analysis were washed with Milli-Q water, freeze dried, and digested with separate digestion steps using ultra-trace grade H_2O_2 and HNO_3 in a Class 100 trace metal workstation within an ISO Level 7 clean room. Digestates were analyzed using a Triple Quadrupole ICP-MS (Agilent 8900) at the Trace Metal Biogeochemistry Laboratory at the University of Miami, RSMAS campus. We use the O_2 mass shift mode on the ICP-QQQ-MS to shift As in the sample away from interferences, permitting more precise measurements of As concentrations. Intensities measured on the ICP-QQQ-MS were calibrated against a series of five Agilent multi-element calibration standards spanning the range of expected concentrations of the targeted major and trace metals in the *Sargassum* compost, as well as Certified Reference Materials (CRM) of known elemental composition. The two CRMs used were Algae Reference (IAEA-392) and Rye Flour (IAEA-V-8). These two references were chosen because they had certified references values for elements of interest and were composed of similar sample matrices. The % accuracy of the digestion approach and these measurements were calculated as reported by Harouaka et al., (2021), and results are reported in Table II.2. Online internal standards (In and Tb) were used in each gas mode to assess measurement quality and instrument drift throughout the analytical run. Results are reported in mg/kg of dry sample weight.

Table II.2: Values collected from ICP-QQQ-MS method compared to IAEA reported values. Based on the expected values, percent accuracy was calculated. An element is considered usable data if the percent accuracy value was above 80%; these elements are distinguished in bold. Other values below this threshold are considered informational data.

Element	IAEA-392 (Algae) (mg/kg)	Accuracy (%)	IAEA-V8 (Rye Flour) (mg/kg)	Accuracy (%)
Al	20.69			
As	0.16	92.33		
Ba	18.91			
Br				
Ca	2243.52	83.71	135.23	90.76
Cd		0.00		
Co	3.09	92.71	0.07	
Cr	4.02	87.86		
Cs				
Cu	20.70	89.24	0.73	76.45
Fe	448.05	90.15	3.20	78.06
K	7242.59	86.40	1546.56	80.34
Mg	1979.55	83.31	92.64	76.56
Mn	61.13	90.56	1.80	87.61
Mo				
Na	487.23	71.65	0.00	
Ni		0.00		
P	4955.82		517.36	87.39
Pb	0.42	73.39	0.05	
Rb	3.69		0.41	85.77
Zn	114.51	89.46	2.19	86.65

The concentration of metals were also evaluated at an outside laboratory (Florida Spectrum Environmental Services). Samples were collected on the last day of the phase I, placed in a Ziploc^{TM} bag, and then frozen at -20°C. They were then dropped off at the lab for further analysis. Florida Spectrum Environmental Services utilized method 3050B (U.S EPA,1996) for sample digestions and 6010B (U.S. EPA, 1996) for sample analysis.

Another method for metals analysis was also used for comparison. This method is called X-ray fluorescence (XRF) and utilized a handheld XRF analyzer (Innov-X Systems Inc., model alpha-2000s). XRF uses X-ray radiation to extract electrons from the atoms in the target sample and reads the wavelength and intensity of the secondary X-rays emitted by the target atoms to identify and quantify each element (Block et al., 2007; Robey et al., 2018). At every sampling event, the compost from the tumbler composter was placed in a cleaned plastic container that was measured 5 cm in diameter by 4.3 cm in height. The compost was compactly packed and then wrapped 5 times in plastic wrap (Glad® ClingWrap). Analysis was performed by placing the XRF against the plastic container wrapped in plastic wrapped surface and using an analytical time of 30 seconds. Detection limits for the handheld XRF was determined by repeated analysis of an empty plastic container on the laboratory table, since the metals of interest were not detected in the plastic container and laboratory table. The XRF provides detection limits for every reading, and these vary with each analysis. In order to determine a typical detection limit, the empty plastic container and laboratory table was analyzed 5 times each sampling event (total of 50 readings were taken); detection limits were recorded and averaged. Fifty readings for each treatment were taken in both phases.

Table II.3: Limits of Detection (LOD) of the analyzed elements using handheld XRF (ppm=mg/kg).

Metal (mg/kg)	LOD
Mn	158
Pb	38
Sb	489
Ti	1405
Ba	684
Cr	241
Fe	179
Co	110
Ni	83
Cu	71
Zn	40
Hg	36
As	24
Se	13
Ag	204
Cd	295
Sn	432

II.2.6 Bacteria Enumeration

Samples for microbe analyses were pre-processed with splits used to prepare two filters (0.45-µm mixed cellulose filters, Pall Industries). One filter was used for analysis of enterococci and the other for fecal coliform.

Compost samples were aseptically mixed using a sterile spoon in the Whirl-Pak™ bags to make the sample as uniform as possible. An aliquot was used to extract enterococci and fecal coliform from the compost according to the procedure described by Boehm et al. (2009), which was adapted to compost samples. In brief, for this method 10 grams of compost were placed into a second pre-weighed Whirl-Pak™ bag. Two hundred mL of sterile phosphate buffered saline solution was added and mixed by rubbing the bag between the thumb and fingertips for 2 minutes and then allowing the solution to settle for 10 minutes. The longer settling time allowed for more of the larger particulates of seaweed to settle out. For both enterococci and fecal coliform analyses, three dilutions were used (10 mL, 1 mL, and 0.1 mL of extract).

Filters for enterococci analysis were cultured on Enterococcus indoxyl-β-D-glucoside (mEI) agar (EPA Method 1600, U.S. EPA 2014) and incubated at 41 ± 0.5 °C for 24 hours. After incubation, colonies that were blue or exhibited a blue halo were counted as positive. Filters for fecal coliform analysis were cultured on mFC agar plates (Standard Methods, Method 9222) with 1% rosolic acid and incubated at 44.5 ± 0.5 °C for 24 hours. After incubation, colonies that were blue or exhibited a blue halo were counted as positive. Results were calculated in units of colony forming units (CFU) per 100 mL.

II.2.7 Radish Bioassay

The compost from each of the four tumbler compartments were then prepared with different ratios of *Sargassum* to potting soil (Coco Perlite Grow Media, Envelor Corporation, Edison, New Jersey). Coco Perlite growth media was chosen since starter fertilizer was not included in the mix. The ratios chosen were 100% *Sargassum* compost, 70% *Sargassum* compost and 30% potting soil, 50% *Sargassum* compost and 50% potting soil, 30% *Sargassum* compost and 70% potting soil, and 100% potting soil. On a small allotment of space, the five treatments were set up in medium sized pots. In each pot, five seeds were placed. The pots were monitored twice a day and watered once a day.

II.2.8 Statistical Analysis

An ANOVA analysis was conducted on the data for phase I. An independent t-test was conducted using SPSS to compare the results from phase II. Differences were evaluated between the four treatments (washed, unwashed, grass clippings, and mulch) for phase I and the two treatments (*Sargassum* and *Sargassum* with vegetative waste) for phase II as well as within time periods (beginning, middle, and end) for each phase. To discuss the results over both phases, which each took 20 weeks to complete, three time periods were outlined, beginning, middle and end. The beginning time period represents the first three sampling efforts of each phase. The second three sampling efforts represent the middle of each phase. Finally, the end represents the last 4 sampling efforts of each phase.

II.3 Results and Discussion

II.3.1 Overall Compost Quality

Throughout the first two weeks of phase one, the *Sargassum*, grass clippings and mulch could still be visually distinguished (top row of photos in Figure II.1). At the end of the 20 weeks the materials were sufficiently broken down and resulted in a dark brown, organic rich compost (bottom row of photos in Figure II.1). At 20 weeks the *Sargassum* and wood chip mix (compartment 4) still had some distinguishable mulch within the pile. The grass clippings from Pile 3 were broken down, but tended to clump together in the end product. The washed and unwashed pile appeared identical except for the higher moisture of the washed *Sargassum* observable at the beginning of the compost process.

Over the course of phase II, the vegetative waste that was added to the pile was still distinguishable at the end of the 20 weeks. There were large palm fronds that did not completely breakdown. The pile with only *Sargassum* resulted in a product that was dark brown, rich in organic matter.

Figure II.1 a) Top set of photos represent the initial start of the tumbler composters. Bottom set of photos are the finished product after 20 weeks. b) The top two photos represent the initial start of the large scale piles Bottom set of photos are the finished product after 20 weeks.

II.3.2 Bulk Physical- Chemical Parameters

During phase I, each of the compost compartments reached a final temperature of 24°C after about 20 weeks. All four treatments followed a similar trend with no significant difference in temperature between the four treatments (Figure II.2, panel a). Similarly for Phase II, there was no significant difference between the *Sargassum* pile and the *Sargassum* with vegetative waste pile. The temperature did reach higher levels in phase II (maximum value of 45°C) than in phase I, likely due to the effects of direct sunlight. The tumbler composters were kept in a shaded well ventilated area.

Moisture content for all four tumbler compost treatments started higher than when it ended after the 20 weeks (Figure II.2, panel b). For the washed treatment, the moisture content was initially 34%, dropped to 28%, and then finally decreased to 21% at the end. There were statistical differences between the measurements taken before and at the end (p=0.002) of the washed treatment. The unwashed treatment began at 31%, stayed constant at 31% for middle period, and then ended at 26%. There were no statistical differences observed in moisture content between the time periods for the unwashed treatment. For the treatment with grass, the moisture at the beginning of the study was 44%, then decreased to 38%, and by the end the moisture dropped to 34%. Statistical differences were noticed for the moisture measurements taken before and at the end (p=0.05) of the sample period. For the mulch treatment, the moisture content started at 38%, decreased to 35%, and ended at 28%. These differences were statistically significant for the measurements taken before and at the end (p=0.019) and at the middle and end (p=0.028).

Between treatments, there were statistical differences between the washed treatment and grass (p=0.001) and mulch treatments (p=0.028). Also, there were differences between the unwashed treatment and grass treatment (p=0.001). Finally for phase I, the grass and mulch treatments were different (p=0.044). During phase II, both treatments followed a similar trend as in phase I. The moisture content of the *Sargassum* treatment began at 37%, decreased to 23% and ended at 17%. For the *Sargassum* and vegetative waste treatment, the moisture content started at 36%, decreased to 35%, and ended at 21%. For phase II there were no differences in moisture between the time periods nor the treatments. Ideally the moisture content should be within 40%-50%, but this was not achieved for both phases of this study. Sand content was high for all the treatments, which can account for the low moisture content since the moisture holding capacity of sand is low (Natural Resources Conservation Service, 2008).

For pH, during phase I, the pH started moderately high for the washed treatment (pH = 9.39), and then increased to 9.57 and stayed constant until the end of the 20 weeks (Figure II.2, panel c). The unwashed treatment started a pH of 9.15, increased to 9.48, and ended at 9.61. For the unwashed samples, there was a statistical difference between the middle and end measurements (p=0.040). The grass treatment started at a pH of 9.07, decreased to 8.84, and finally increased to 8.93. The pH of the mulch treatment began at 9.14 and then increased to 9.55 and slightly decreased to 9.54. Within the treatments, there were statistical differences between the grass treatment and washed (p=<0.001), unwashed (p=0.003), and mulch treatments (p=0.005). The differences can be due to the pH of grass clippings. During phase II, the pH of the *Sargassum* pile began at 8.6 and continuously increased to 9.3 and 9.5. Within the *Sargassum* and vegetative waste pile, the pH began at 8.7 and increased to 9.0 and 9.3. There were no statistical differences within the time periods for each pile. There were no differences between the piles as well ($p=0.663$).

For conductivity, during phase I, conductivity started off low (between 100 to 400 µS/cm) and then began to increase in all four treatments (Figure II.2, panel d). As the decomposition progressed, it was expected that the salts naturally found in *Sargassum* would begin to accumulate. As expected, the washed pile displayed a lower conductivity than the rest of the treatments. Conductivity started off at 145 µS/cm, slightly decreased to 140 µS/cm and finally increased back up to 195 µS/cm. The unwashed treatment started at 359 µS/cm, increased to 525 µS/cm and finally decreased to 475 µS/cm. The grass treatment started at 364 µS/cm, decreased slightly to 358, and then increased to 578 µS/cm. The mulch treatment started at 373 µS/cm, decreased to 352 µS/cm, and finally increased to 583 µS/cm. There were no statistical differences over the time periods across all treatments. Mulch and grass treatments displayed higher conductivities overall than the washed and unwashed treatments. Within the treatments, the washed treatment was statistically different than the unwashed ($p<0.001$), grass, ($p<0.001$) and mulch ($p<0.001$). There were no other differences observed within the treatments. During phase II, both piles displayed high conductivities and then decreased over time. For the *Sargassum* pile, the conductivity started off at 2010 µS/cm, then decreased to 713 µS/cm, and finally to 180 µS/cm. Within the time periods outlined, there were statistical differences between measurements taken at the end compared to the beginning ($p=0.050$) and middle ($p=0.007$). Similarly, for the *Sargassum* and vegetative waste pile, the conductivity started at 1860 µS/cm, decreased to 457 µS/cm, and finally decreased to 273 µS/cm. There were statistical differences between the measurements taken at the beginning compared to the middle ($p=0.040$) and end ($p=0.009$). Between the two piles, there were no differences observed. These piles were exposed to the atmosphere and rain was allowed to “wash” the pile

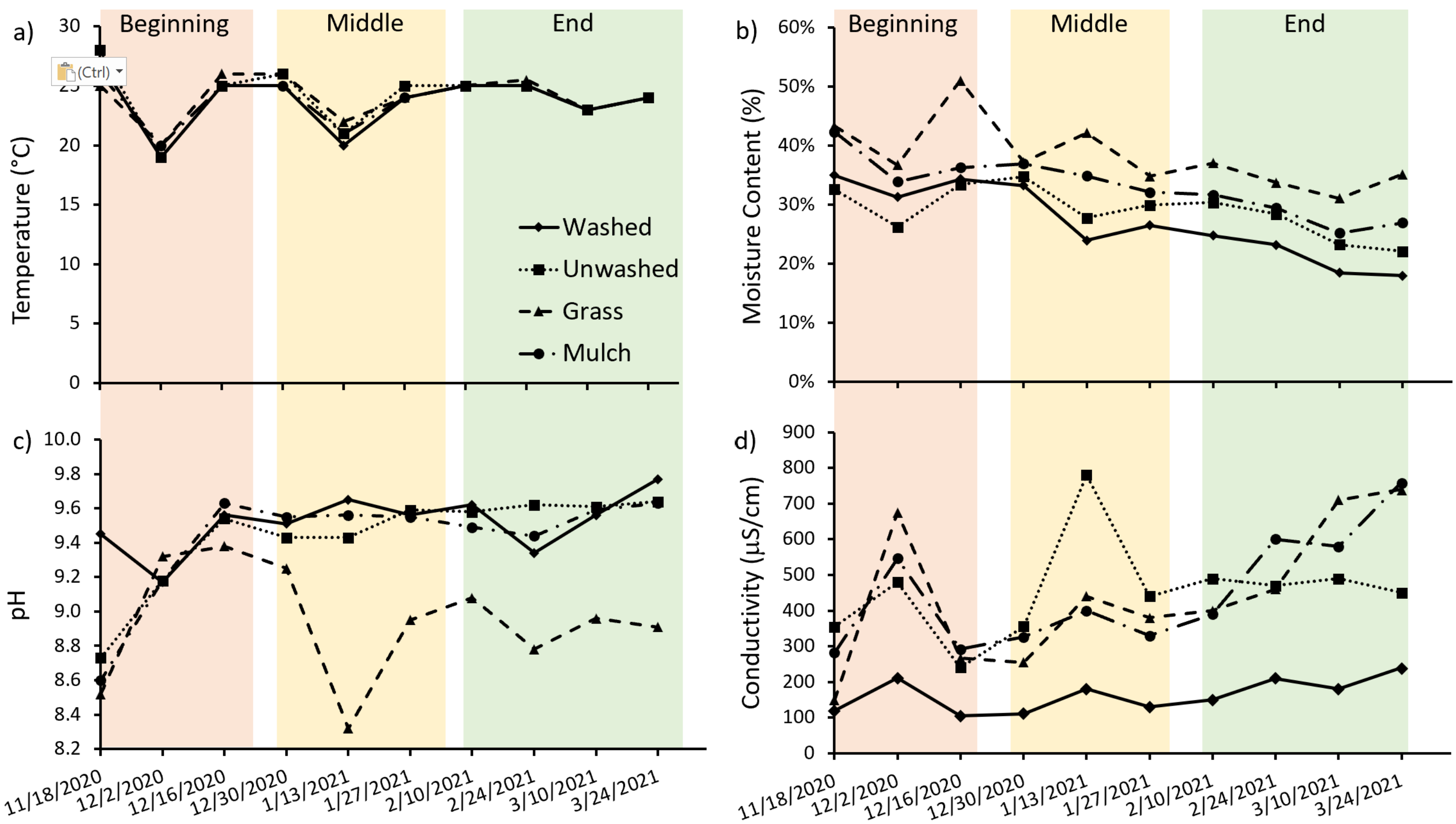

Figure II.2: Time series of the bulk physical- chemical parameters for phase I. The time periods that were used for the analysis are shown with shaded boxes. Red depicts the beginning period, yellow depicts the middle period, and green depicts the end stage after 20 weeks. a) Temperature b) Moisture content c) pH d) Conductivity

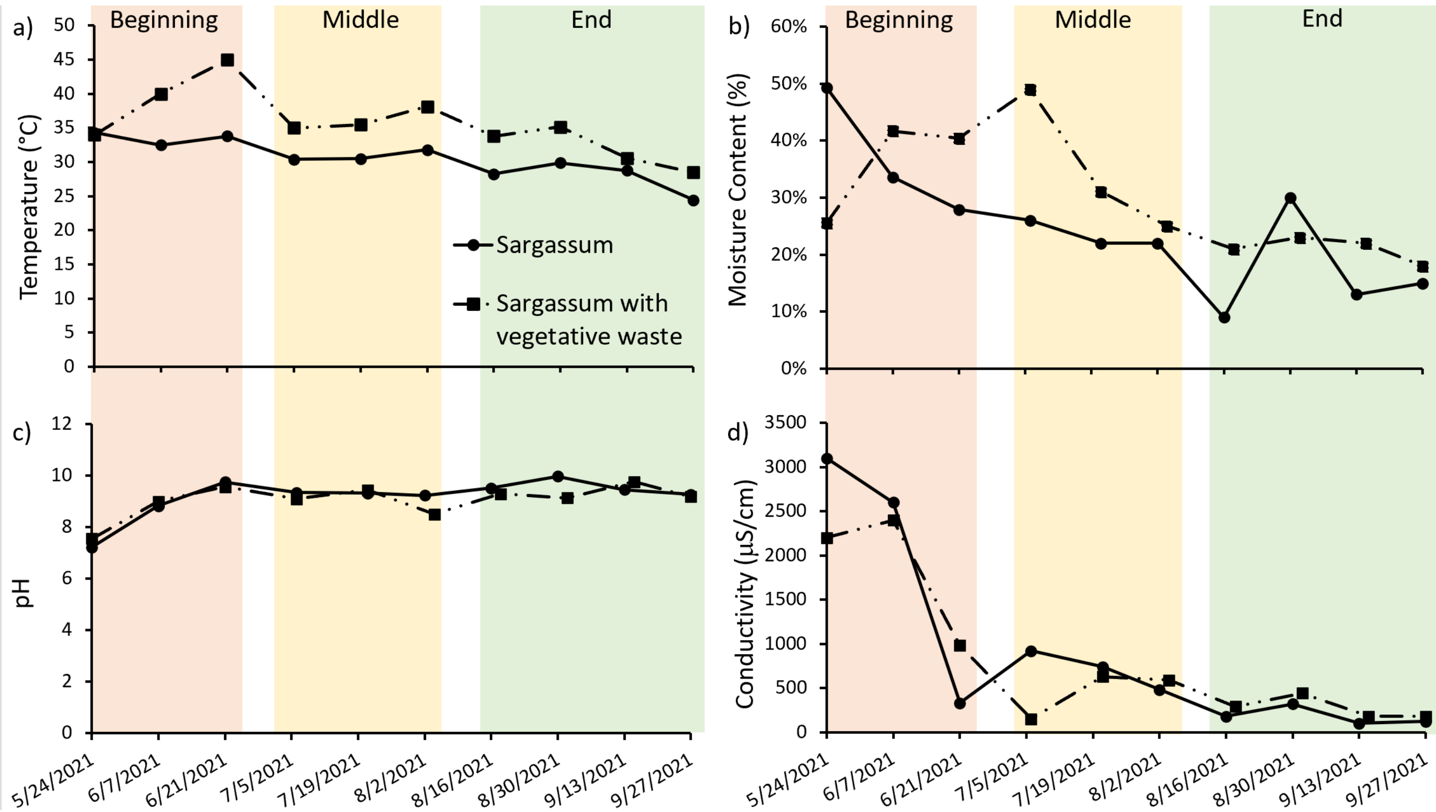

Figure II.3: Time series of the bulk physical- chemical parameters for phase II. The time periods that were used for the analysis are shown with shaded boxes. Red depicts the beginning period, yellow depicts the middle period, and green depicts the end stage after 20 weeks. a) Temperature b) Moisture content c) pH d) Conductivity

II.3.3 Nutrients

During phase I, the compost subjected to the washed treatment and the unwashed treatments were similar in phosphorus concentrations. The compost that was washed ranged from 211 mg/kg to 751 mg/kg, while the unwashed compost ranged from 208 mg/kg to 677 mg/kg. Phosphorus was consistently higher in the grass treatment than the other three treatments. For the grass treatment, the range of phosphorus was 231 mg/kg to 4389 mg/kg. The sample collected on 12/2/2020, had the highest phosphorus value of 4389 mg/kg. In the mulch treatment, phosphorus concentrations were similar to the washed and unwashed treatments. When looking at all the treatments, there were statistical differences between grass and washed ($p=0.002$), unwashed ($p=0.002$), and mulch ($p=0.001$). Differences with the grass treatments can be accounted for because of the origin of the grass. The grass clippings were collected after a lawn was cut. This lawn is known to have fertilizer added to it, thus accounting for the higher levels of phosphorus in the grass clippings treatment.

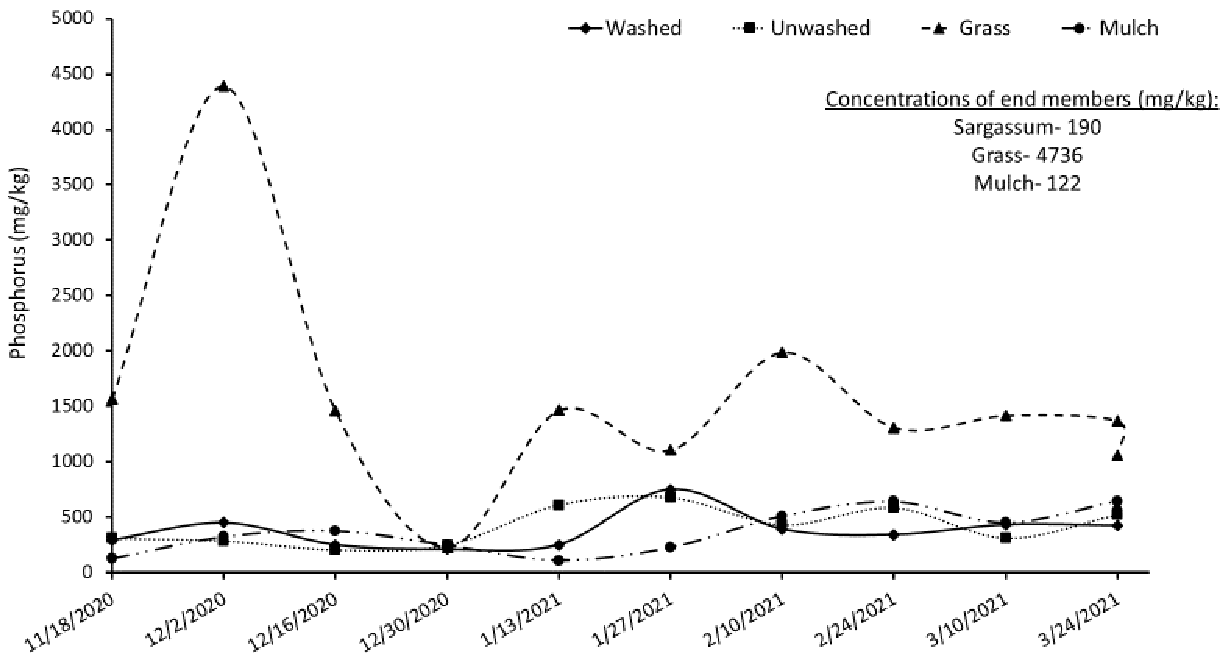

Figure II.4: Phosphorus levels during phase I.

On average the C:N ratios were higher in the mulch treatment than the other treatments (70.0) whereas the grass treatment was consistently low (27.7). As expected, the washed and unwashed treatments followed similar trends. Within the treatments, there were statistical differences between the washed treatment compared to the grass (p=0.036) and mulch (p=0.009) treatments, as well as between the mulch treatment compared to the unwashed (p<0.001) and grass treatments (p<0.001). The mulch treatment had a higher C:N overall because mulch is known to have a high carbon level. During phase II, there was a difference between the *Sargassum* pile and *Sargassum* with vegetative waste pile (p=0.002). C:N of the *Sargassum* pile averaged 34, 24, and 33 for the beginning, middle, and end respectively. For the *Sargassum* with vegetative waste, C:N were 45, 41, and 40 for the beginning, middle, and end respectively.

End members of pure *Sargassum*, grass, and mulch were also examined. Summary of findings of end members can be found in Appendix A.

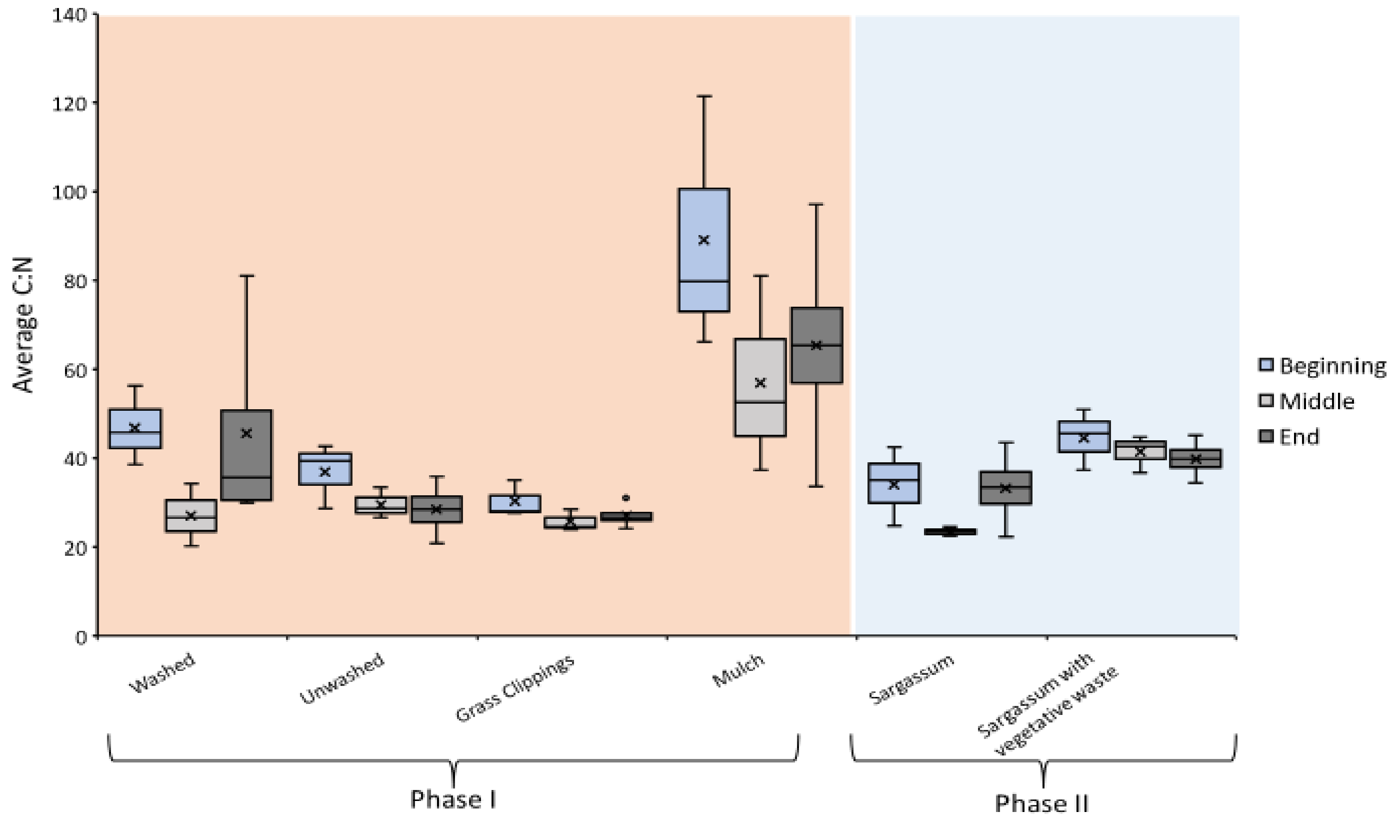

Figure II.5: Boxplots representing C:N ratios for the four treatments in phase I and the two treatments in phase II across the time periods of beginning, middle, and end. Phase I is shown with the light red background, while phase II shown with the light blue background.

II.3.4 Metals by traditional laboratory atomic level methods

Twenty-two metals were detected in the samples sent to the outside laboratory. Results from the lab are summarized in the table below (Table II.4). Arsenic is a notorious and toxic metalloid, ubiquitous in the environment and is a metalloid of concern and is regulated by the U.S. EPA and FDEP. Other studies (Dassié et al., 2021; Davis et al., 2021; Devault et al., 2020; Milledge & Harvey, 2016; Milledge et al., 2020; Ortega-Flores et al., 2022; Rodríguez-Martínez et al., 2020) have detected arsenic in *Sargassum* spp. Arsenic can be found in the range of 13-53.5 mg/kg dry weight in *Sargassum spp.* (Fernandez et. Al., 2017). Specifically in South Florida, *S. fluitans* was observed to have arsenic concentrations of 116-119 mg/kg and *S. natans* was observed to vary between 90-103 mg/kg (Collado-Vides et al., 2020). Pure *Sargassum* for the current study contained 38.9 mg/kg of arsenic. Differences in between elemental results can also be attributed to variations in the proportions of each component.

During phase I, arsenic concentrations in compost ranged from 9.89-12.1 mg/kg. The unwashed, grass clippings, and mulch treatments had similar values, while the lower value was found in the washed sample. During phase II, the concentration of arsenic in the *Sargassum* pile was 7.0 mg/kg and 8.3 mg/kg for the pile of *Sargassum* with vegetative waste. It was expected that the unwashed and washed treatments would have similar arsenic concentrations, but for most sampling efforts, they varied greatly from each other. Unwashed and grass treatments tended to have higher levels of arsenic overall. Within the treatments, there were statistical differences in arsenic concentrations between the unwashed treatment compared to grass ($p=0.006$) and mulch ($p=0.010$) treatments.

Twenty-one other metals were measured, and results are provided in Table II.4.

Table II.4 Results of the 22 metals detected in pure Sargassum and in compost (20 weeks). Results from Florida-Spectrum Environmental Services. Pure grass and mulch samples were analyzed using ICP-QQQ-MS.

Pollutant (mg/kg, dry weight)	Pure Sargassum	Pure Grass	Pure Mulch	Phase I Compost				Phase II Compost	
				Washed	Unwashed	Grass Clippings	Mulch	Sargassum	Sargassum with vegetative waste
Aluminum	84.4	42.99	34.34	248	133	141	137	378	184
Arsenic	38.9	0.05	-	9.89	12.1	11.4	12.0	7.02	8.30
Barium	14.5	13.32	1.34	7.05	7.92	9.53	7.97	9.69	11.8
Boron	121	25.11	5.42	43.6	63.0	64.7	55.2	28.0	54.0
Calcium	120,000	10,814	6910	125,000	132,000	126,000	125,000	149,000	137,000
Chromium	3.00	0.33	0.10	3.53	3.05	3.16	3.09	4.27	3.90
Copper	1.99	9.52	1.87	1.02	1.10	1.79	1.07	5.20	3.87
Iron	481	122.4	33.69	931	900	881	845	1400	866
Lead	0.446	0.16	0.12	0.71	0.683	0.742	0.696	3.48	1.62
Lithium	5.01	NM	NM	7.62	7.33	7.27	7.10	10.9	7.82
Magnesium	7780	2208	285.08	3020	3460	3460	3170	3750	5200
Manganese	9.15	16.24	6.17	9.57	9.38	11.8	10.0	15.4	23.9
Nickel	1.01	0.36	-	0.696	0.78	0.777	0.736	0.878	0.83
Total Phosphorus	430	4739	122.42	202	227	522	396	331	598
Potassium	19,500	9899	863.25	1920	3250	4050	3240	526	1180
Silicon	93.9	3125	232	85.8	80.8	80.6	87.3	148	97.8
Sodium	19,400	10356	11.81	4700	6670	6470	6390	2980	3440
Strontium	1600	126.19	4.91	1060	1200	1160	1110	1320	1490
Sulfur	5170	3125	232	1360	2100	2290	1990	749	1210
Titanium	1.54	-	-	2.44	1.97	2.18	2.16	4.00	2.94
Vanadium	2.42	0.13	0.04	3.21	3.30	3.13	3.05	2.98	2.87
Zinc	7.66	102.3	7.20	4.60	4.93	10.2	4.92	24.2	18.8

To further evaluate the arsenic levels, the results for phase I were further broken down by time periods (Table II.5). When breaking the phase I results by time periods, values from samples analyzed by the Trace Metal Biogeochemistry Laboratory were used. Results show that concentrations of arsenic were within the same order of magnitude throughout the experiment and between experiments. Arsenic levels observed in the tumbler compost compartments of

Sargassum, whether washed or unwashed, were high (8.93 to 30.1 mg/kg). The value reported in Table II.5 were slightly higher than those in Table II.4, which are from the outside laboratory.

Table II.5: Arsenic concentration (mg/kg) of the four treatments

	Washed (mg/kg)	Unwashed (mg/kg)	Grass (mg/kg)	Mulch (mg/kg)
Beginning	17.25	17.64	13.36	12.93
Middle	13.69	20.98	10.11	8.62
End	13.42	22.91	15.75	16.62

Overall, there were 42 elements that were detected using ICP-QQQ-MS. Of these 42, 12 elements exhibited recovery levels of 80% or better of the reference material (Table II.2). Mg, P, K, Ca, Cr, Mn, Fe, Co, Cu, Zn, and As were detected in 100% of the samples, while Rb was only detected in 95% of samples. Mg was lowest in the grass and mulch treatments overall, while higher in the washed and highest in the unwashed treatments. P concentrations were the highest overall in the grass treatment, with levels ranging from 934 mg/kg – 2473 mg/kg. The end member of grass and *Sargassum* initially had P concentrations of 4739 mg/kg and 190 mg/kg respectively. K concentrations fluctuated over the time periods. Ca concentrations were the highest out of the 12 elements, with the highest concentrations in washed samples (95,900 mg/kg - 113,600 mg/kg).

Three of the 12 elements are regulated by the USCC, U.S. EPA, and FDEP. Limits of these elements are outlined in Table II.9. Cu and Zn were well below the limits established by these agencies, while As varied. In accordance with the USCC and U.S. EPA, As concentrations were within regulatory limits of 41 mg/kg and 75 mg/kg, respectively. Levels of As did not exceed 22.9 mg/kg when looking at the time periods. Consistently the unwashed treatment had higher levels. Under the FDEP SCTL, As risks are minimal for levels below 2.1 mg/kg for residential use and 12 mg/kg for commercial use. These SCTLs limits were not achieved in any of the treatments during phase I.

Table II.6: Twelve elements that exhibited recovery levels of 80% or better of reference materials. Each treatment was broken down into time periods of beginning, middle and end. Elements in bold are monitored by the USCC, U.S. EPA, and FDEP (The FDEP compost criteria does not include arsenic limits. The FDEP includes arsenic within its SCTLs.)

Elements (mg/kg dw)	Beginning				Middle				End			
	Washed	Unwashed	Grass Clippings	Mulch	Washed	Unwashed	Grass Clippings	Mulch	Washed	Unwashed	Grass Clippings	Mulch
Mg	7089	7336	5234	4592	7379	9287	3915	3430	6697	9555	7138	7918
P	331	268	2473	275	405	512	934	196	398	463	1428	561
K	4227	7549	5385	3549	2881	4975	1487	2052	2277	5413	3065	4298
Ca	95,908	72,494	70,129	71,138	103,397	96,753	107,338	70,756	113,638	86,823	93,997	69,470
Cr	3.05	1.72	2.21	2.42	2.70	2.49	3.05	2.23	3.57	1.97	2.56	2.48
Mn	11.88	7.04	22.16	10.94	11.57	13.33	15.77	10.68	13.91	12.63	21.65	14.99
Fe	808	416	626	624	651	568	873	534	862	785	619	516
Co	0.53	0.58	0.30	0.52	0.53	0.72	0.23	0.30	0.46	0.67	0.46	0.55
Cu	2.60	2.37	6.35	1.90	3.07	3.91	3.28	1.16	2.90	11.88	7.65	3.33
Zn	11.30	9.21	43.30	8.73	12.54	16.51	22.34	5.71	12.38	19.82	44.98	15.77
As	17.25	17.64	13.36	12.93	13.69	20.98	10.11	8.62	13.42	22.91	15.75	16.62
Rb	1.96	3.16	2.54	1.58	1.74	2.13	0.86	0.90	1.03	2.10	1.49	1.81

II.3.5 Metals by XRF

Four of the 21 elements were detected by XRF in the small scale tumbler composter samples (Table II.7). These elements were strontium, iron, zinc, and arsenic. Out of the four metals detected, strontium and iron were consistent in all samples. Arsenic was detected in the unwashed (2% of readings) and mulch treatment (4% of readings), but not in the washed and grass clippings treatment. Zinc was only detected in a fraction of the grass clippings treatment samples (16% of readings).

Table II.7: Average elemental concentrations determined by XRF in four treatments of phase I. Results are expressed as mg/kg of biomass. Non detected values were not considered in the average for detected elements.

Treatment	Element	Concentration (mg/kg)
Washed	Sr	608
	Fe	250
	Zn	ND
	As	ND
Unwashed	Sr	607
	Fe	220
	Zn	ND
	As	11
Grass	Sr	470
	Fe	183
	Zn	35
	As	ND
Mulch	Sr	586
	Fe	191
	Zn	ND
	As	9

ND-Not Detected

Eight of 21 elements were detected in phase II using the handheld XRF method. Table II.8 summarizes the elemental concentrations detected. Strontium and iron were again consistently detected in both treatments. Lead was detected in 10% of the readings for the *Sargassum* treatment and only 8% of the *Sargassum* for the vegetative waste treatments. Copper was detected in 6% of the readings for the *Sargassum* treatment. Interestingly, zinc was detected in both treatments (8%- *Sargassum*, 2%- *Sargassum* with vegetive waste). Antimony and silver were also detected in the samples but not on a consistent basis. Antimony and silver were detected in 2% of the readings for both the *Sargassum* and *Sargassum* with vegetive waste treatments. Silver was detected in 6% of the readings for the *Sargassum* treatment. Arsenic was only detected in the *Sargassum* treatment. Strontium and iron levels were higher in phase II compared to phase I.

Table II.8: Mean elemental concentrations determined by XRF in two treatments of phase II. Results are expressed as mg/kg of biomass.

Element	*Sargassum* (mg/kg)	*Sargassum* with vegetative waste (mg/kg)
Pb	21	22
Sr	1204	1028
Sb	243	216
Fe	728	590
Cu	52	ND
Zn	26	26
As	17	ND
Ag	135	114

ND-Not Detected

II.3.5 Comparison with Guidelines

Based on the guidelines outlined by the USCC, soluble salts should be in the recommended range of 1000-10,000 µS/cm. From the results above, during phase I, none of the treatments were within the recommended range of the USCC. Contrary to original concerns about salts, the conductivity of the samples were below the recommended levels as dictated by the USCC. According to the Klock-Moore and Fitzpatrick (1999), however, the recommended electrical conductivity of foliage plants should be within 570- 1430 µS/cm and woody ornamentals within 500- 1000 µS/cm. The grass clippings and mulch treatment were within both recommended ranges. Even though the washed and unwashed treatments were not within either of the mentioned ranges, a usable product was still produced in terms of the ability to support the growth of plants. The concentration of soluble salts in the compost from phase II were not within either of the ranges as well and were too low. This can be accounted for by the constant washing of the pile from the rain.

In terms of the C:N ratios that are recommended by the USCC, levels should be <20. During phase I and phase II, this range was not achieved. Instead, in the four treatments for phase I and two treatments for phase II, levels were higher. The mulch treatment had the highest C:N ratio of 65 in the end. Similarly, during phase II, the C:N in the pile with the added vegetative waste was higher at a level of 40 in the end.

Elemental concentrations were compared to four different guidelines, the USCC, the U.S. EPA, FDEP compost criteria, and FDEP SCTLs (Table II.9). It should be noted that arsenic, chromium, mercury, and molybdenum are not regulated under the FDEP criteria for compost. Arsenic measured as part of phase I were within two of the three agency guidelines. It did not meet the FDEP SCTLs for neither residential nor commercial use. Samples generated from phase II met the guidelines for arsenic, except for the FDEP residential use SCTL.

Table II. 9: Comparison of four standards for metals and results from phase I and II

Pollutant	**USCC**	**U.S. EPA**	**FDEP-Criteria for the use of compost**	**FDEP-Direct Exposure (Soil Cleanup Target Levels)**		**Phase I ICP-OES Scan**				**Phase II ICP-OES Scan**		
	Must meet the EPA testing limits for heavy metals (mg/kg)	Ceiling Concentration Limits for all biosolids applied to land (mg/kg)	The total amount of heavy metal applied to soils (pounds per acre)	Residential (mg/kg)	Commercial/ Industrial (mg/kg)	Washed (mg/kg)	Unwashed (mg/kg)	Grass Clippings (mg/kg)	Mulch (mg/kg)	*Sargassum* Pile (mg/kg)	*Sargassum* with vegetative waste (mg/kg)	Pure *Sargassum* collected on 5/24/21 (mg/kg)
Arsenic	41	75	*	2.1	12	13	22	15	16	7.02	8.3	38.9
Cadmium	39	85	4.45	82	1,700	NM	NM	NM	NM	NM	NM	NM
Chromium	*	3,000	*	210	470	3.53	3.05	3.16	3.09	4.27	3.9	3
Copper	1,500	4,300	111	150	89,000	1.02	1.1	1.79	1.07	5.2	3.87	1.99
Lead	300	840	445	400	1,400	0.71	0.683	0.742	0.696	3.48	1.62	0.446
Mercury	17	57	*	3	17	NM	NM	NM	NM	NM	NM	NM
Molybdenum	*	75	*	440	11,000	NM	NM	NM	NM	NM	NM	NM
Nickel	420	420	111	340	35,000	0.696	0.778	0.777	0.736	0.878	0.834	1.01
Selenium	100	100	*	440	11,000	NM	NM	NM	NM	NM	NM	NM
Zinc	2,800	7,500	222	26,000	630,000	4.6	4.93	10.2	4.92	24.2	18.8	7.66

*Not Regulated
NM-Not measured

II.3.6 Radish Bioassay Results

Overall, most of the four treatments and various additions of potting soil were able to produce radish plants. The only treatment that did not have growth was the 100% mulch treatment. From Figure II.6, the overall best treatment was grass clippings. Of the total 20 seeds planted, all 20 sprouted. There is a difference that is noticed between the washed and unwashed treatments. The plants appear to be healthier in the washed treatment compared to the unwashed. All of the treatments have grown more than the control. When comparing the 100% compost treatment, the treatment that yielded the best results were the grass clippings. Following the grass clippings treatment, the unwashed treatment yielded the next best results, followed by the washed treatment and finally the mulch treatment.

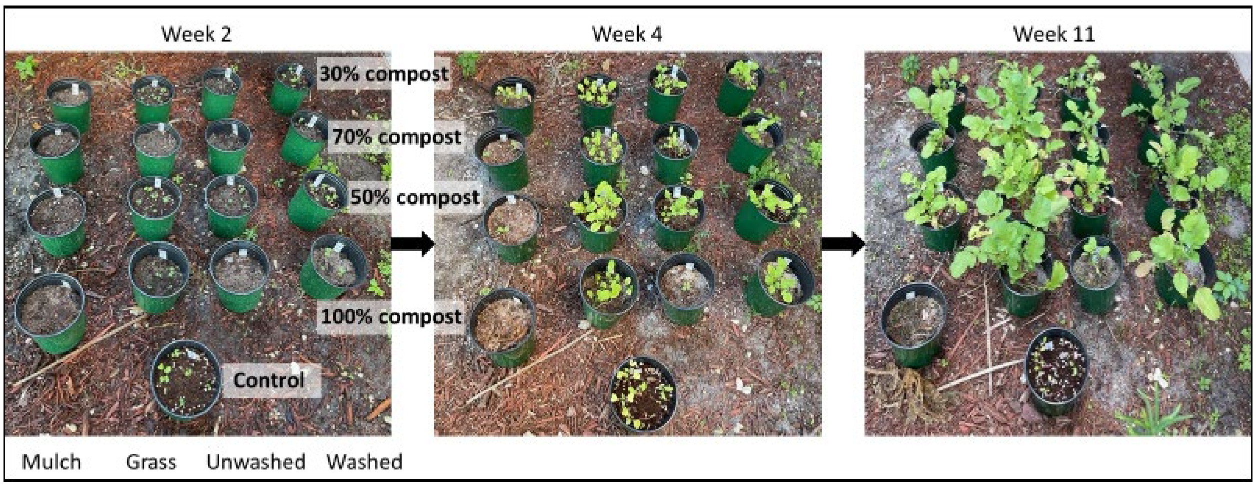

Figure II.6: Progression of the radish bioassay. In each picture, from left to right the columns represent the treatments as follows, mulch, grass clippings, unwashed, and washed. The rows from top to bottom are as follows 30% compost, 70% compost, 50% compost, and 100% compost. The planter in the middle represents the control of 100% potting soil.

CHAPTER III

SUMMARY AND CONCLUSIONS

CHAPTER III

SUMMARY AND CONCLUSIONS

III.1 Summary and Conclusions

Overall, this study showed that *Sargassum* can be diverted from landfill disposal and used to produce compost. The compost that was produced is a usable product in terms of bacteria levels, metals, and ability to support the growth of radish plants. Even though the compost produced might not be within the standards outlined by the USCC, the product is still able to support plant growth. Surprisingly the conductivity was below the recommended range outlined by the USCC so washing of the *Sargassum* is not necessary for its use as compost. The alkaline pH and bacteria levels were not within the recommended range of the USCC. The larger scale experiments at the City of Hallandale Beach did meet the bacteria levels outlined by the U.S.EPA, while the smaller scale treatment did not. C:N for both phases were higher than what was recommended by the USCC. The treatment in phase I that had the highest C:N ratio was the mulch additive treatment. This treatment also had the slowest and least radish plant growth. Similarly in phase II, the *Sargassum* with vegetative waste treatment did have a higher C:N ratio than the *Sargassum* pile. Finally, the last parameter, elemental composition displayed interesting results. Arsenic, which is a metalloid of concern, was detected in both phases. Even though it was detected, it was within two of the three regulatory standards outlined. Overall, results show that a useable compost product can be produced from *Sargassum* in terms bacteria levels, metals, and application of growing plants.

III.2 Recommendations

Results from this study serve as a starting point for outlining new standards for *Sargassum* compost in the State of Florida. Ideally there should be standards specific for compost and specific for compost made of *Sargassum spp.* or for *Sargassum spp.* mixtures (i.e., yard waste). 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 the current study, the economics behind operating a *Sargassum* composting facility should be examined further.

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.

REFERENCES AND PERTINENT LITERATURE

"Compost Chemistry." *Compost Chemistry - Cornell Composting*, Cornell Composting , 1996, compost.css.cornell.edu/chemistry.html.

"Compost Needs-Moisture ." *Compost Fundamentals: Compost Needs - Moisture*, Washington State University- Extension , whatcom.wsu.edu/ag/compost/fundamentals/needs_moisture.htm.

"Compost Needs-Aeration." *Compost Fundamentals: Compost Needs - Aeration*, Washington State University- Extension , http://whatcom.wsu.edu/ag/compost/fundamentals/needs_aeration.htm.

" Listing of Halophytes & Salt-Tolerant Plants." *Salt-Tolerant Plants*, 2020, www.biosalinity.org/salt- tolerant_plants.htm.

"Monitoring Compost PH." *Monitoring Compost PH - Cornell Composting*, 1996, compost.css.cornell.edu/monitor/monitorph.html.

"Sargassum: A Resource Guide for the Caribbean."Caribbean Alliance for Sustainable Tourism. Resource Guide. 2015.

"Tourism down 30-35% Due to Sargassum: Playa Del Carmen Mayor-Elect." *Mexico News Daily*, 5 Aug. 2018, mexiconewsdaily.com/news/tourism-down-30-35-due-to-sargassum/.

Alexander, Ron. "Phosphorus And Compost Use Dynamics." *BioCycle*, Dec. 2016, www.biocycle.net/2016/12/12/phosphorus-compost-use-dynamics/.

Atkin, Emily. "Humans Have Created a New Natural Disaster." *The New Republic*, 29 Aug. 2018, newrepublic.com/article/150775/humans-created-new-natural-disaster.

Block, C. N., Shibata, T., Solo-Gabriele, H. M., & Townsend, T. G. (2007). Use of handheld X-ray fluorescence spectrometry units for identification of arsenic in treated wood. *Environmental Pollution*, *148*(2), 627–633. https://doi.org/10.1016/j.envpol.2006.11.013

Christopher, Thomas, and Marty Asher. *Compost This Book!: the Art of Composting for Your Yard, Your Community, and the Planet*. Sierra Club Books, 1994.

Cruz-Rivera, E., Flores-Díaz, M., & Hawkins, A. (2015). A fish kill coincident with dense *Sargassum* accumulation in a tropical bay. *Bulletin of Marine Science*, *91*(4), 455–456. https://doi.org/10.5343/bms.2015.1048

Dassié, E. P., Gourves, P. Y., Cipolloni, O., Pascal, P. Y., & Baudrimont, M. (2021). First assessment of Atlantic open ocean Sargassum spp. metal and metalloid concentrations. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-021-17047-8

Davis, D., Simister, R., Campbell, S., Marston, M., Bose, S., McQueen-Mason, S. J., Gomez, L. D., Gallimore, W. A., & Tonon, T. (2021). Biomass composition of the golden tide pelagic seaweeds Sargassum fluitans and S. natans (morphotypes I and VIII) to inform valorisation pathways. *Science of The Total Environment*, *762*, 143134. https://doi.org/10.1016/j.scitotenv.2020.143134

Devault, D. A., Pierre, R., Marfaing, H., Dolique, F., & Lopez, P. J. (2020). Sargassum contamination and consequences for downstream uses: a review. *Journal of Applied Phycology*, *33*(1), 567–602. https://doi.org/10.1007/s10811-020-02250-w

FDEP , “Table II - Soil Cleanup Target Levels for Rule 62-777,” Rule 62-777, Florida Department of Environmental Protection, Florida, 2013.

Gondek, Matthew D, et al. “A Review of Soluble Salts in Compost.” *Environmental Research and Innovation Center University of Wisconsin Oshkosh*, University of Wisconsin Oshkosh, 2019.

Huffard, C. L., von Thun, S., Sherman, A. D., Sealey, K., & Smith Jr, K. L. (2014). Pelagic Sargassum community change over a 40-year period: temporal and spatial variability. Marine biology, 161(12), 2735-2751.

Klock-Moore, Kimberly Anne, and George Fitzpatrick. “Management of Urban Waste Compost Amendments in Ornamental Production Systems in Florida.” *Soil and Crop Science Society of Florida*, vol. 59, 1999, pp. 14–16.

Langin, K. (2018). Seaweed masses assault Caribbean islands. *Science*, *360*(6394), 1157–1158. https://doi.org/10.1126/science.360.6394.1157

Lapointe, Brian E., et al. “Ryther Revisited: Nutrient Excretions by Fishes Enhance Productivity of Pelagic Sargassum in the Western North Atlantic Ocean.” *Journal of Experimental Marine Biology and Ecology*, vol. 458, 2014, pp. 46–56., doi:10.1016/j.jembe.2014.05.002.

Lapointe, B. E., Brewton, R. A., Herren, L. W., Wang, M., Hu, C., McGillicuddy, D. J., Lindell, S., Hernandez, F. J., & Morton, P. L. (2021). Nutrient content and stoichiometry of pelagic Sargassum reflects increasing nitrogen availability in the Atlantic Basin. *Nature Communications*, *12*(1). https://doi.org/10.1038/s41467-021-23135-7

Richard, Tom. “Temperature .” *Temperature*, 2000, compost.css.cornell.edu/Factsheets/FS5.html.

Milledge, J. J., Maneein, S., Arribas López, E., & Bartlett, D. (2020). Sargassum Inundations in Turks and Caicos: Methane Potential and Proximate, Ultimate, Lipid, Amino Acid, Metal and Metalloid Analyses. *Energies*, *13*(6), 1523. https://doi.org/10.3390/en13061523

Ortega-Flores, P. A., Serviere-Zaragoza, E., de Anda-Montañez, J. A., Freile-Pelegrín, Y., Robledo, D., & Méndez-Rodríguez, L. C. (2022). Trace elements in pelagic Sargassum species in the Mexican Caribbean: Identification of key variables affecting arsenic accumulation in S. fluitans. *Science of The Total Environment*, *806*, 150657. https://doi.org/10.1016/j.scitotenv.2021.150657

Resiere, D., Valentino, R., Nevière, R., Banydeen, R., Gueye, P., Florentin, J., Cabié, A., Lebrun, T., Mégarbane, B., Guerrier, G., & Mehdaoui, H. (2018). Sargassum seaweed on Caribbean islands: an international public health concern. *The Lancet*, *392*(10165), 2691. https://doi.org/10.1016/s0140-6736(18)32777-6

Robey, N. M., Solo-Gabriele, H. M., Jones, A. S., Marini, J., & Townsend, T. G. (2018). Metals content of recycled construction and demolition wood before and after implementation of best management practices. *Environmental Pollution*, *242*, 1198–1205. https://doi.org/10.1016/j.envpol.2018.07.134

Rodríguez-Martínez, R. E., Roy, P. D., Torrescano-Valle, N., Cabanillas-Terán, N., Carrillo-Domínguez, S., Collado-Vides, L., García-Sánchez, M., & van Tussenbroek, B. I. (2020). Element concentrations in pelagic Sargassum along the Mexican Caribbean coast in 2018–2019. *PeerJ*, *8*, e8667. https://doi.org/10.7717/peerj.8667

Sembera, Jen A., et al. "Composting as an Alternative Management Strategy for Sargassum Drifts on Coastlines." HortTechnology, vol. 28, no. 1, 2018, pp. 80–84., doi:10.21273/horttech03836-17.

Swinscoe, Isobel, et al. "The Seaweed Fly (Coelopidae) Can Facilitate Environmental Survival and Transmission of E. Coli O157 at Sandy Beaches." *Journal of Environmental Management*, vol. 223, 2018, pp. 275–285., doi:10.1016/j.jenvman.2018.06.045.

U.S. EPA, "A Plain English Guide to the EPA Part 503 Biosolids Rule," EPA-832-R-9-003, U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC, USA, 1994.

U.S. EPA, "Enterococci in water by membrane filtration using membrane-Enterococcus indoxyl-β-D-glucoside Agar (mEI)," EPA-821-R-14-011, United States Environmental Protection Agency, Washington, DC, USA, 2014.

U.S. EPA, "Biosolids Technology Fact Sheet Land Application of Biosolids," EPA 832-F-00-064, United States Environmental Protection Agency, Washington, DC, USA, 2000.

U.S. EPA. 1996. "Method 3050B: Acid Digestion of Sediments, Sludges, and Soils," Revision 2. Washington, DC.

U.S. EPA. 1996. “Method 6010B: Inductively Coupled Plasma-Atomic Emission Spectrometry” Revision 2. Washington, DC.

Walsh, K. T., & Waliczek, T. M. (2020). Examining the Quality of a Compost Product Derived from Sargassum. *HortTechnology*, *30*(3), 331–336. https://doi.org/10.21273/horttech04523-19

Wang, Mengqiu, et al. “The Great Atlantic Sargassum Belt.” *Science*, vol. 365, no. 6448, 2019, pp. 83–87., doi:10.1126/science.aaw7912.

APPENDIX A

END MEMBER ANALYSIS

End members were analyzed to assess the background levels of C:N ratios of the pure *Sargassum*, grass, and mulch. Initially when evaluating the C:N ratios of the samples, it was brought to our attention that the samples did not follow a trend and fluctuated in values. One of the possible reasons for this fluctuation is the heterogeneity of the samples. Primarily there were three end members used to create the four compost treatments during phase I. But since the *Sargassum* was not screened to ensure that only *Sargassum* was added, other materials could have impacted the C:N ratios of the compost. One other possible end member that could have impacted the results is seagrass which is commonly stranded at south Florida beaches along with *Sargassum*.

Thus, a mix of *Sargassum*, grass, mulch, and seagrass (henceforth will be called mixed sample) were created to analyze whether seagrass was in the original sample collected from the beach. Approximately 150 mg of each end member was measured, combined, and well mixed before weighing for analysis. A binocular microscope was used to examine the characteristics of each end member (Figure A.1-A.4). Once the end members were recognizable, the mixed sample was also examined under the binocular microscope (Figure A.5). Counts of each of the end members can be seen in figure A.6.

Isotopic composition of each end member was collected and summarized in Table A.1. Theoretical values were estimated based on the count of each end member and the isotopic concentration of known end members.

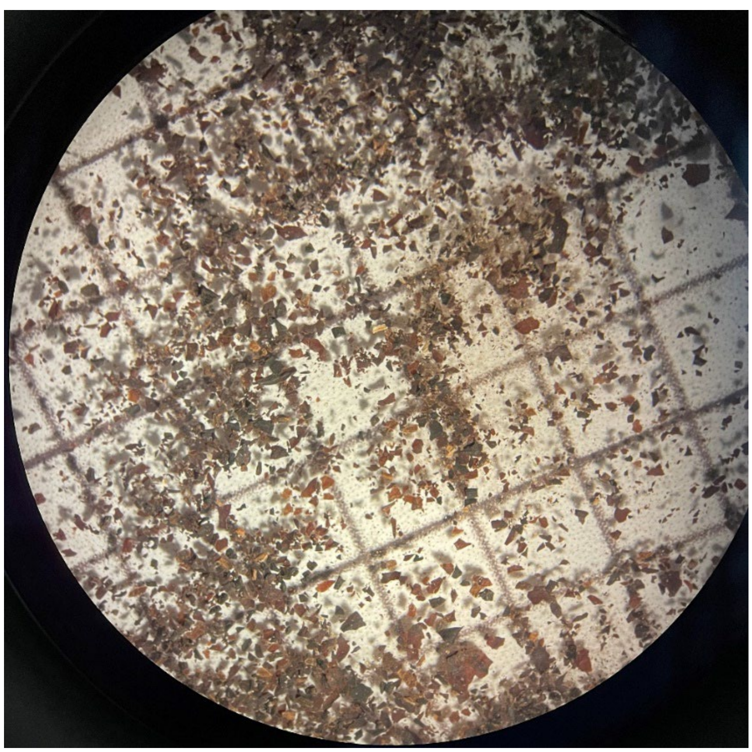

Figure A.1: Pure *Sargassum* collected

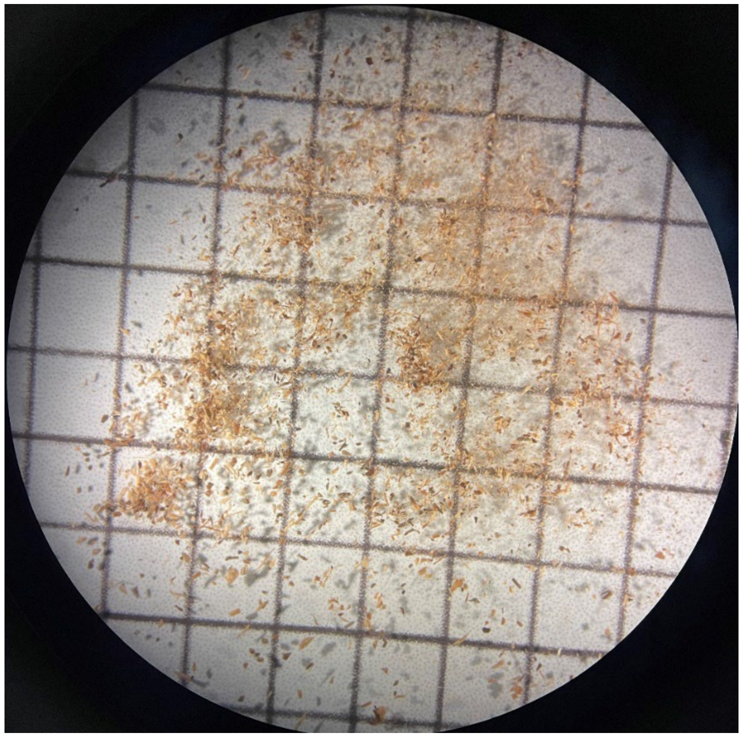

Figure A.2: Pure Mulch

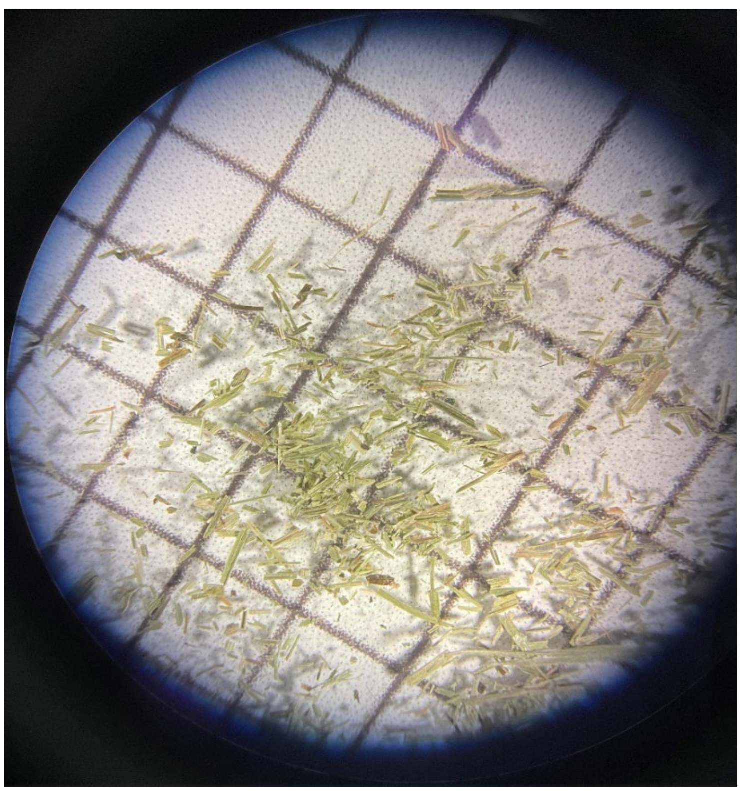

Figure A.3: Pure Grass

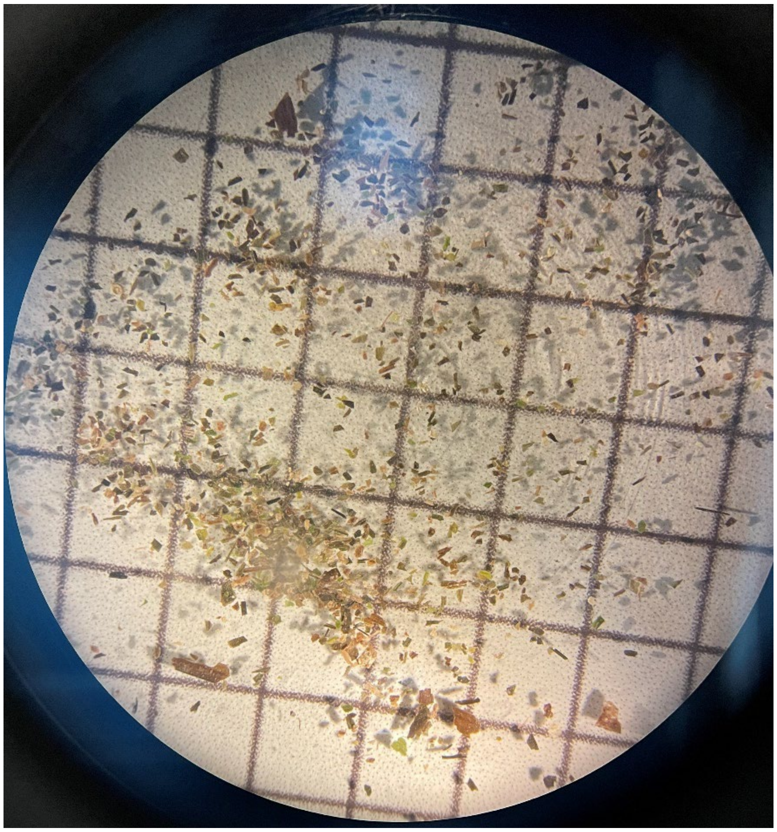

Figure A. 4: Pure Seagrass

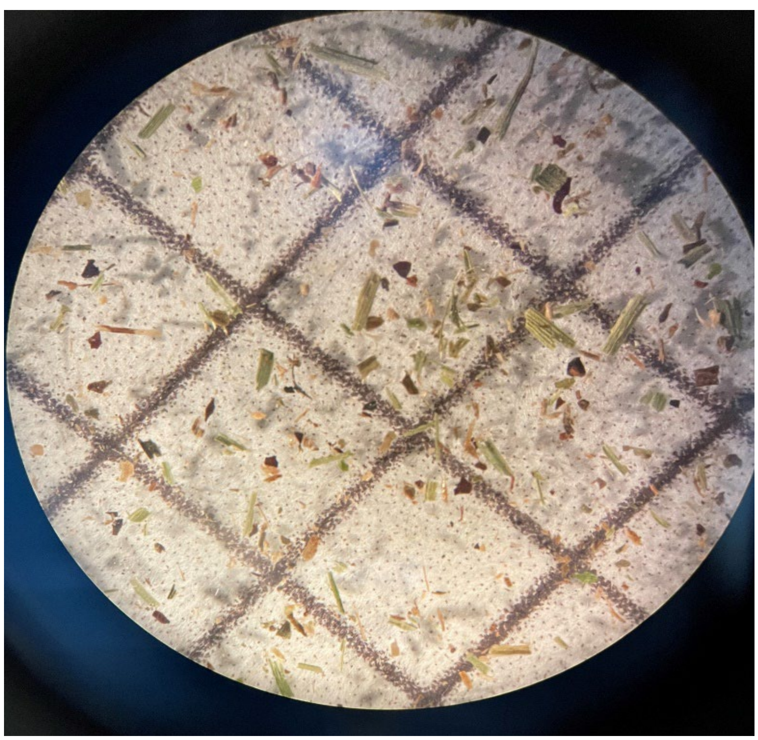

Figure A.5: Mixed Sample of Seagrass, *Sargassum*, Grass, and Mulch

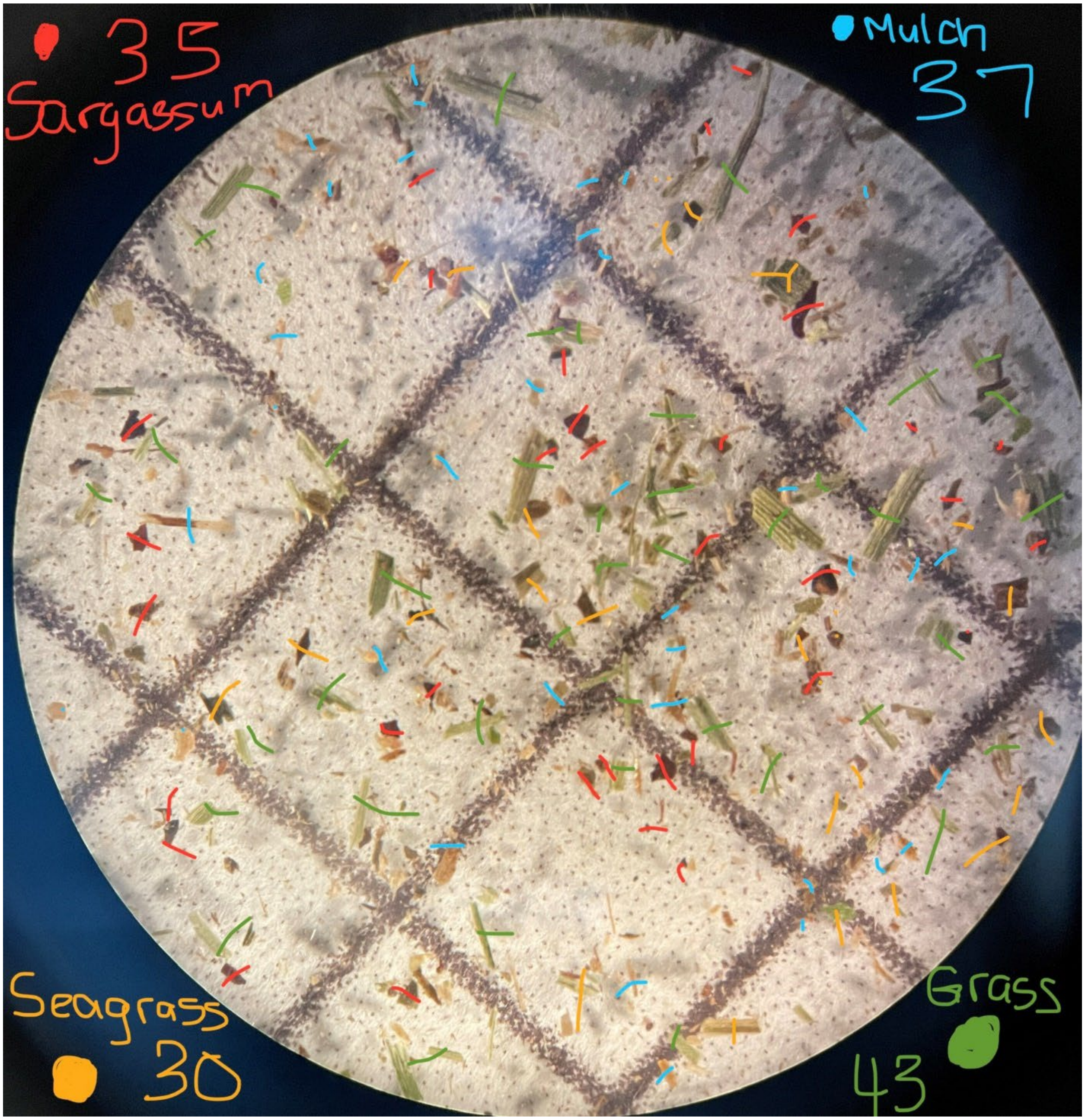

Figure A.6: Counts of each end member.

Mass Balance:

Table A.1: Summary of isotopic composition of each end member.

End Members	Count from Microscope Picture	Fraction	Fraction (%)	$\delta^{15}N$	$\delta^{13}C$	N	C	C:N
Sargassum	35	0.24	24%	-0.31	-14.30	0.83	33.84	47.50
Grass	43	0.30	30%	1.73	-12.16	2.31	39.76	20.06
Mulch	37	0.26	26%	-0.32	-25.91	0.36	47.24	152.99
Seagrass	30	0.21	21%	4.33	-10.27	1.17	29.08	28.97
Theoretical values	145	1.00	100%	**1.25**	**-15.79**	**1.22**	**38.03**	**62.45**
Mixed Sample				**1.48**	**-16.42**	**0.98**	**36.49**	**47.12**

$$\%\,Sargassum + \%Grass + \%Mulch + \%Seagrass = \%\,Total$$

$$\left(\frac{35}{144}\right) \times 100 + \left(\frac{43}{144}\right) \times 100 \left(\frac{37}{144}\right) \times 100 \left(\frac{30}{144}\right) \times 100 = 100\%$$

$$24\% + 30\% + 26\% + 21\% = 100\%$$

Isotopic Composition

$$f_{Sargassum}\delta^{13}_{Sargassum}C + f_{Grass}\delta^{13}_{Grass}C + f_{Mulch}\delta^{13}_{Mulch}C + f_{Seagrass}\delta^{13}_{Seagrass}C = f_{TV}\delta^{13}_{TV}C$$

$$(0.24)(-14.30) + (0.30)(-12.16) + (0.26)(-25.91) + (0.21)(-10.27) = (1)(x)$$

$$x = -15.79$$

$$f_{Sargassum}\delta^{15}_{Sargassum}N + f_{Grass}\delta^{15}_{Grass}N + f_{Mulch}\delta^{15}_{Mulch}N + f_{Seagrass}\delta^{15}_{Seagrass}N = f_{TV}\delta^{15}_{TV}N$$

$$(0.24)(-0.31) + (0.30)(1.73) + (0.26)(-0.32) + (0.21)(4.33) = (1)(x)$$

$$x = 1.25$$

APPENDIX B

OVERALL COMPARISON OF COMPOST PARAMETERS WITH REGULATIONS

Table B.1: Comparison of standards to measurements of compost parameters during phase I and II. Nonhighlighted boxes mean that the guidelines were not met. Green highlighted boxes mean that the parameter was met for USCC and U.S EPA guidelines. Yellow highlighted boxes mean that the parameters were met for all guidelines. Bold elements experienced an 80% recovery of certified reference materials, while the other elements are informational values. Pink highlighted boxes mean that the bacteria levels were achieved.

Parameter	USCC Standards (mg/kg)	U.S EPA (mg/kg)	FDEP-Criteria for the use of compost (lbs/acre)	FDEP-Direct Exposure (Soil Cleanup Target Levels)		Washed	Unwashed	Grass clippings	Mulch	Sargassum	Sargassum with vegetative waste
				Residential	Commercial/ Industrial						
pH	5.0-8.5					9.57	9.61	8.93	9.53	9.55	9.33
Moisture Content (%)	40-50					21%	26%	34%	28%	17%	21%
Soluble Salts (mS/cm)	1000-10000					195	475	578	583	180	273
C:N	<20					45.66	28.52	27.14	65.39	27.54	35.26
Arsenic	41	75		2.1	12	13.42	22.91	15.75	16.62	TBD	TBD
Copper	1500	4300	111	150	89000	2.90	11.88	7.65	3.33	TBD	TBD
Zinc	2800	7500	222	26000	630000	12.38	19.82	44.98	15.77	TBD	TBD
Cadmium	39	85	4.45	82	1700	0.08	0.16	0.13	0.19	TBD	TBD
Nickel	420	420	111	340	35000	2.81	2.85	3.56	2.22	TBD	TBD
Lead	300	840	445	400	1400	0.70	1.11	1.03	1.24	TBD	TBD
Molybdenum		75	-	440	11000	-	-	-	-		
Mercury	17	57	-	3	17	-	-	-	-		
Selenium	100	100	-	440	11000	-	-	-	-		
Fecal coliform (MPN)		<1000				4715	1095	8202	1161	211.2	272

TBD- measures are still being collected.