INVESTIGATING A COMPOSTING MANAGEMENT SYSTEM FOR BROWN ALGAE *(SARGASSUM FLUITANS* AND *SARGASSUM NATANS)*

Kevin Walsh and Tina Marie Waliczek
Texas State University
San Marcos, Texas

Purpose

This project examined large-scale compost management of *Sargassum fluitans* and *Sargassum natans* (brown algae, or Sargassum, collectively).

- Possibility of replicating compost recipes in seaside communities burdened by the plant.

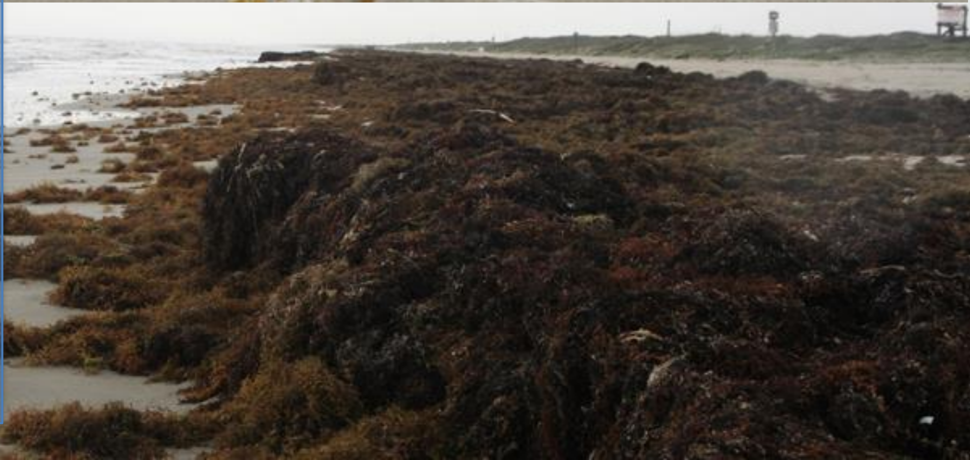
- Investigates limits of Sargassum as a feed stock to create a marketable byproduct.

Objectives

- Develop a large-scale composting system that utilizes the Sargassum biomass with typical feedstocks used in composting.
- To determine the maximum allowable proportion of dried Sargussum to other feedstocks that results in a quality compost product.
- To examine the effect of potentially high levels of salinity from the Sargassum on the final product.
- To develop a management system that can be replicated by the communities that are affected by the problematic species.
- To determine if the composted byproduct is a safe, marketable product for the agricultural and horticultural consumers.

Background: Sargassum

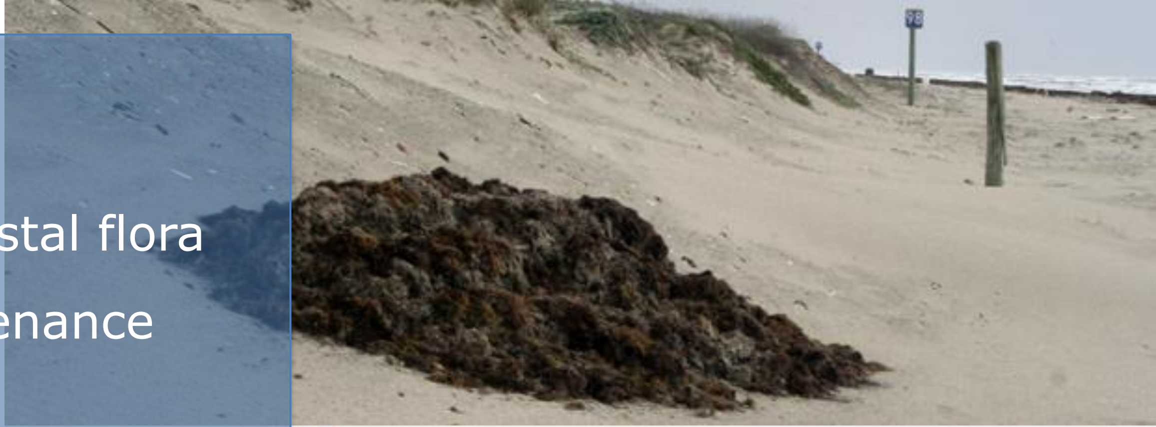
- 2 planktonic species drift onto Texas coastline
    - *S. fluitans*
    - *S. natans*
- Seasonal drifts occur during tourist season.
- Decomposes quickly once on shore.
- *S. fluitans* added to the Global Invasive Species Database.

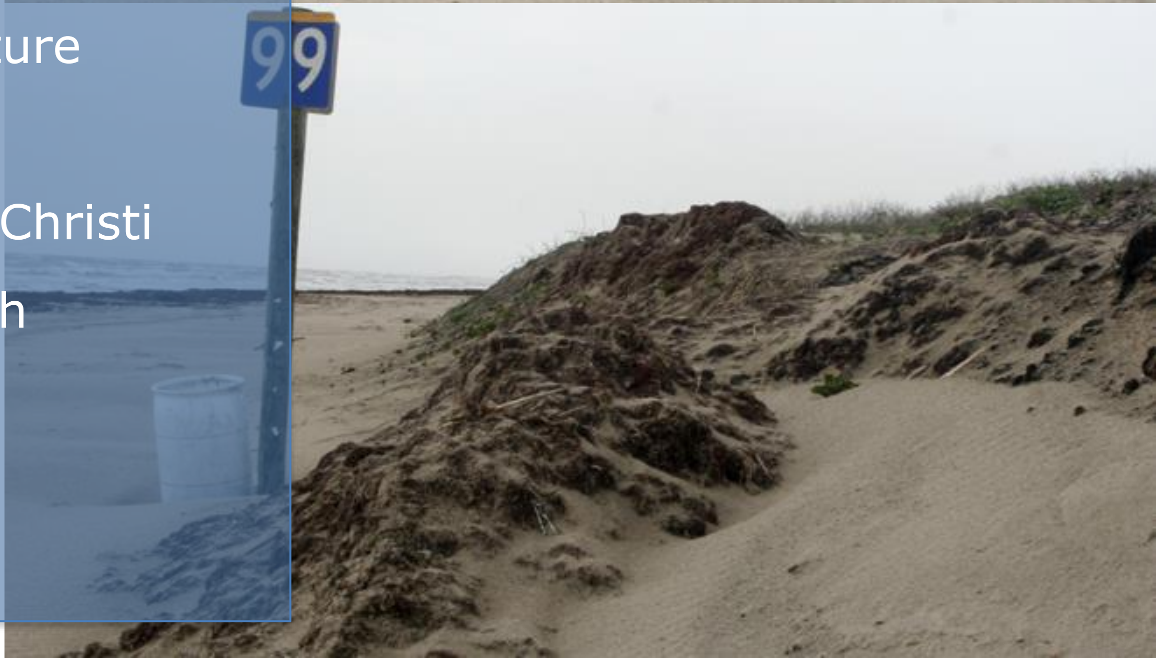


Background: Value

- Natural fertilizer for coastal flora
- Restorative dune maintenance after hurricanes
- Historical use in agriculture

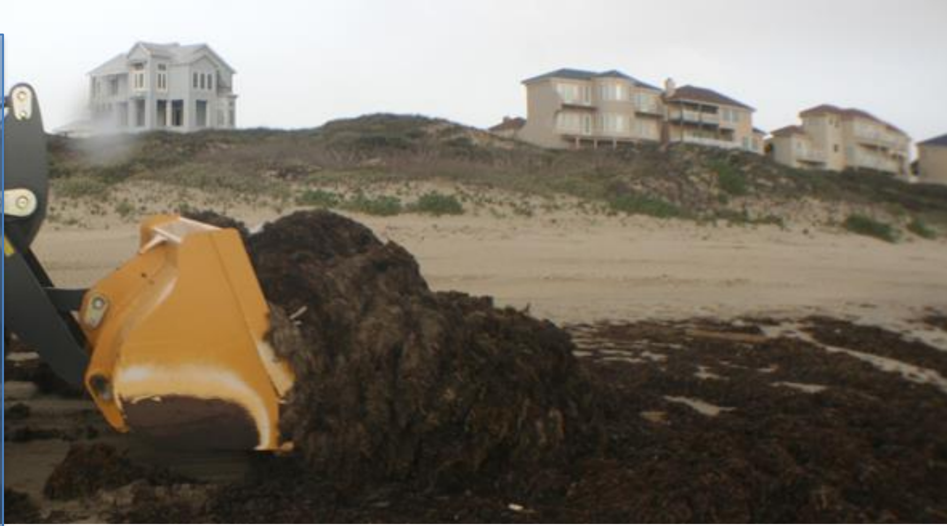
- Management at Corpus Christi
    - Raked into the beach
    - Rebuild foredunes
    - Disposal in landfill

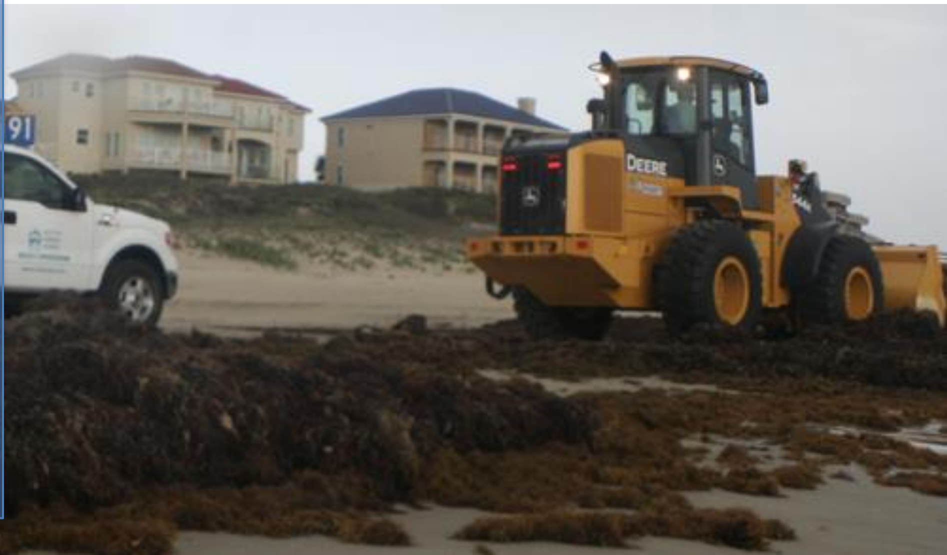




Materials and Methods: Harvesting

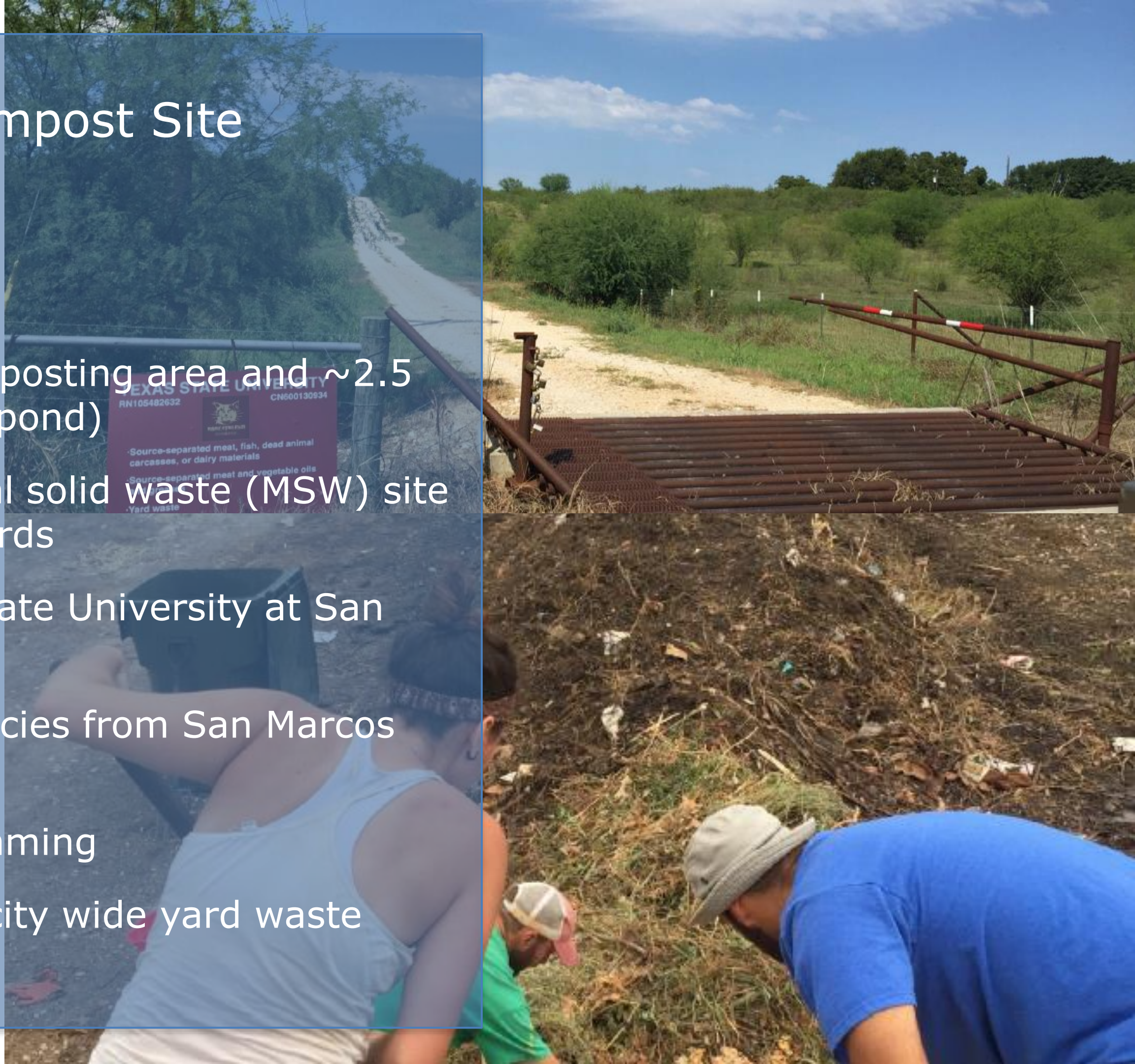
- Collected by front end loader
  - Mustang Island State Park
  - Corpus Christi Parks & Recreation Department.
- Turtle Patrol
  - Kemp’s Ridley sea turtles





Materials and Methods: Compost Site

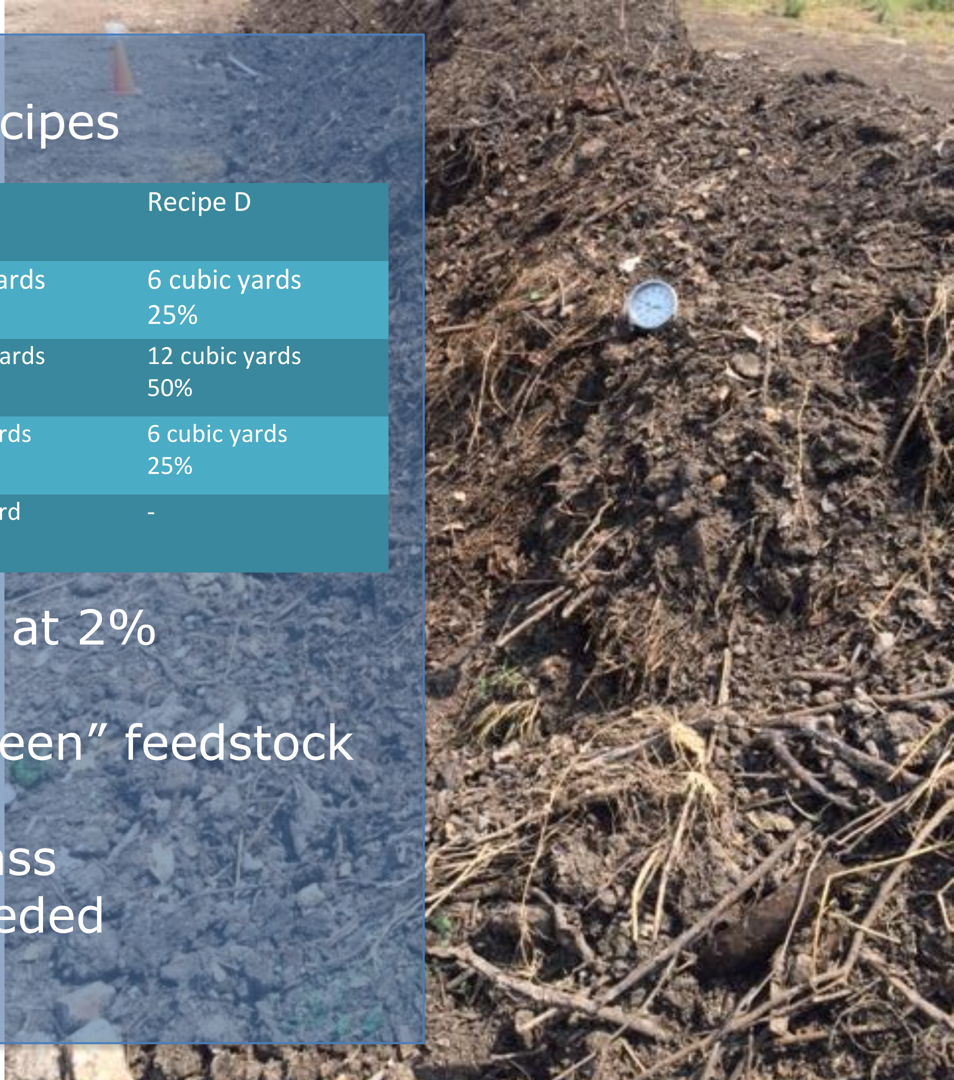
- Bobcat Blend compost site
  - 5 acres
    - (~ 2.5 acres for composting area and ~2.5 acres for catchment pond)
  - Fully functioning municipal solid waste (MSW) site according to TCEQ standards
  - Food waste from Texas State University at San Marcos, TX
  - Fish waste of invasive species from San Marcos river
  - Wood chips from tree trimming
  - Leaf litter collected from city wide yard waste collections



Materials and Methods: Compost Recipes

	Recipe A	Recipe B	Recipe C	Recipe D
Food Waste	4 cubic yards 16.6%	3 cubic yards 12.5%	5 cubic yards 20.83%	6 cubic yards 25%
Wood Chips and Leaf Litter	10 cubic yards 41.6%	10 cubic yards 41.6%	12 cubic yards 50%	12 cubic yards 50%
Sargassum	10 cubic yards 41.6%	10 cubic yards 41.6%	6 cubic yards 25%	6 cubic yards 25%
Fish Waste	-	1 cubic yard 4.16%	1 cubic yard 4.16%	-

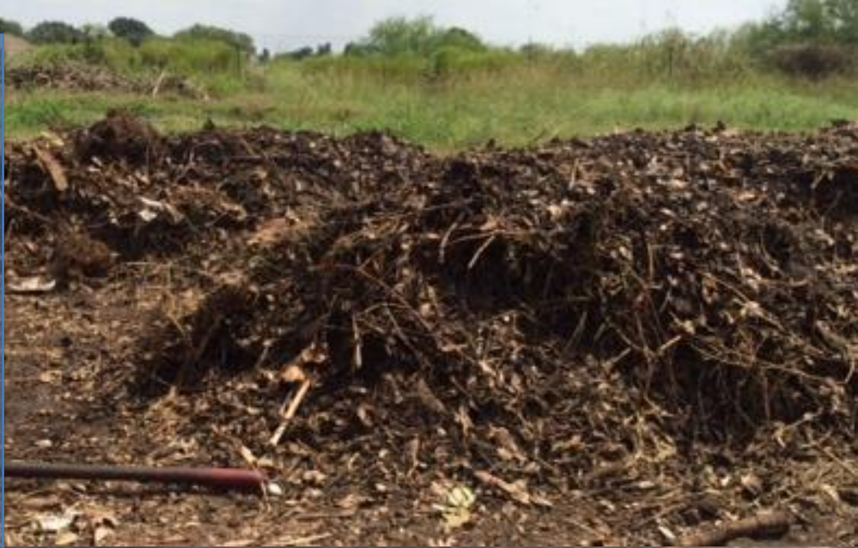
- Previous study tested Sargassum at 2%
- Sargassum initially treated as "green" feedstock
    - Significant dry down of biomass
    - Additional Nitrogen inputs needed

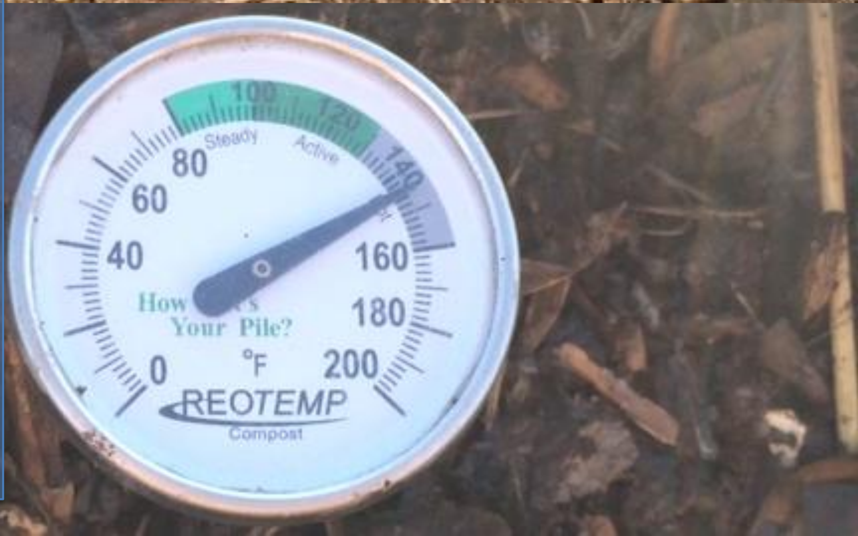


Materials and Methods: Monitoring

- 24-inch Moisture Meter, Lincoln Irrigation, Lincoln NE
- Soil pH Tester, Kel Instruments Co., Wyckoff, NJ
- 60-inch Compost Thermometer Probe, ReoTemp Instrument Co., San Diego, CA

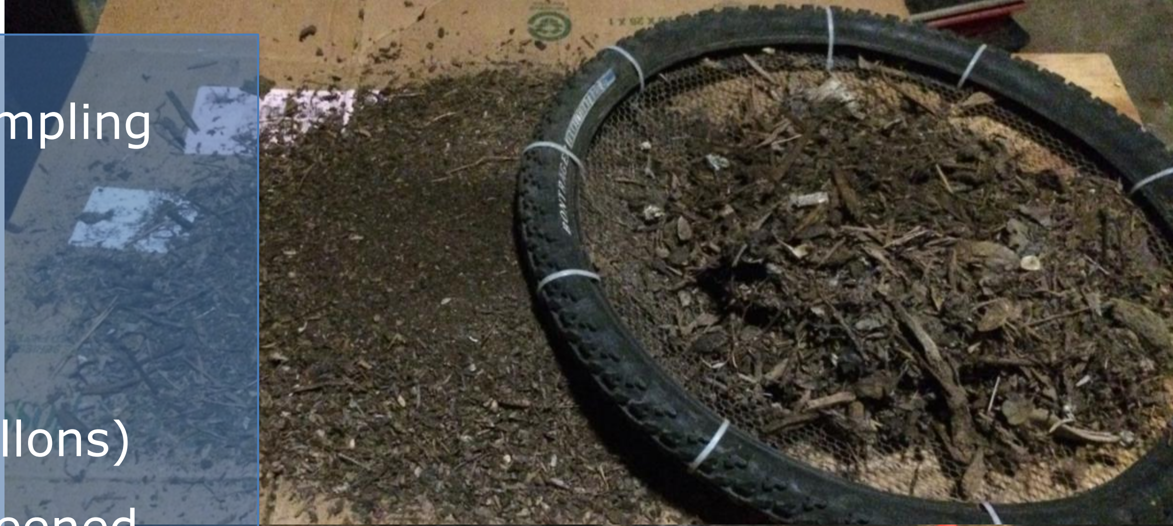
	Recipe A	Recipe B	Recipe C	Recipe D
Moisture	40-60%	40-60%	40-60%	40-60%
pH	5.5-7.5	5.0 -7.5	4.5-8.0	5.0-8.0
Active Stage Temperature	63 C/145 F	63 C/145 F	63 C/145 F	63 C/145 F

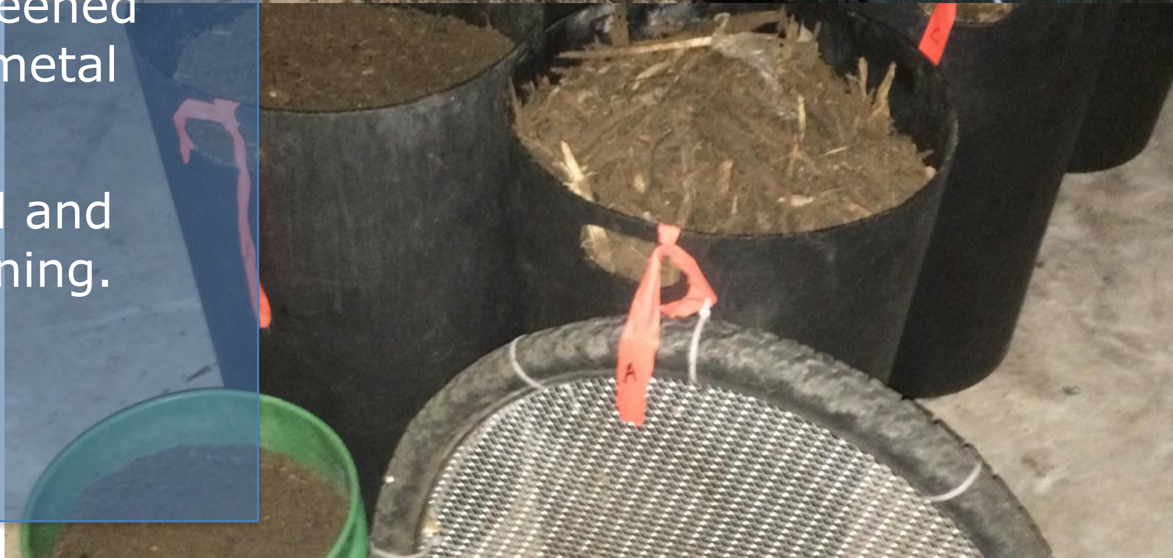




Materials and Methods: Sampling

- Samples taken from 3 different depths at 15 locations.
  - 170.3 Liters (45 gallons)
- Composite samples screened through ¼” expanded metal sheeting.
- Noted presence of sand and other solids after screening.



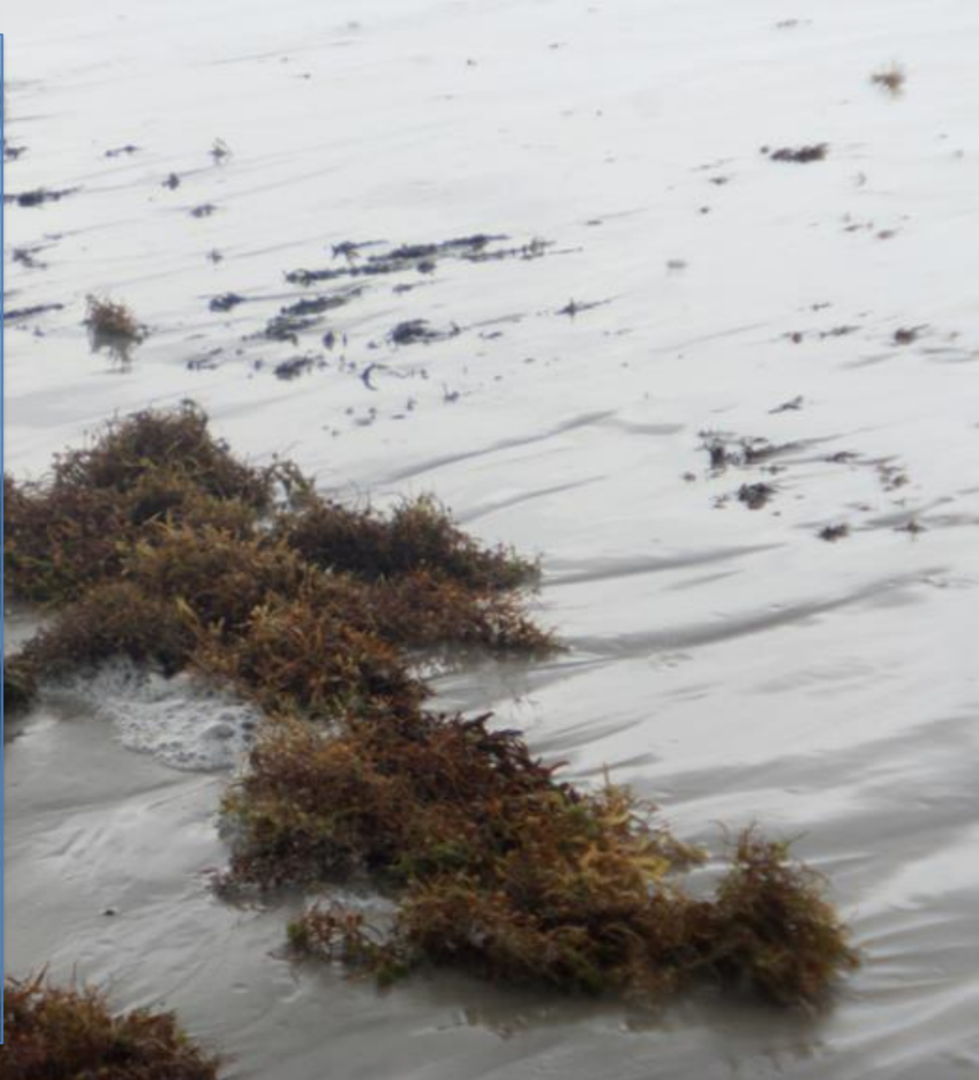


Test Results

	Results (As is basis)				Results (Dry weight basis)				Normal Range
Variable (Units)	A	B	C	D	A	B	C	D	
pH	7.3	7.3	7.8	7.2					5.0-8.5
Soluble Salts (mmhos/cm)	2.92	4.2	3.87	3.01					1.0-10
Solids (%)	63.6	65.4	69.2	71.2					50-60
Moisture (%)	36.4	34.6	30.8	28.8					40-50
Organic Matter (%)	13.74	23.81	17.94	15.43	21.6	36.4	25.9	21.7	30-70 (dry)
Total Nitrogen (%)	0.534	1.019	0.805	0.752	0.84	1.56	1.16	1.06	.5-2.5 (dry)
Carbon (%)	8.014	15.409	10.655	10.457	12.6	23.6	15.4	14.7	<54(dry)
Carbon to Nitrogen (C:N) Ratio	15	15.1	13.2	13.9	15	15.1	13.2	13.9	<20 (dry)
Phosphorus (%)	0.2998	0.5504	0.5517	0.6155	0.471	0.842	0.797	0.864	
Potassium (%)	0.2226	0.3172	0.3145	0.3051	0.35	0.49	0.45	0.43	
Calcium (%)	7.6428	12.1925	9.9456	8.7006	12.02	18.66	14.37	12.22	
Magnesium (%)	0.2513	0.3035	0.2798	0.2321	0.4	0.46	0.4	0.33	
Sulfur (%)	0.1127	0.1515	1450	0.1294	0.18	0.23	0.21	0.18	
Sodium (mg/kg)	896.97	1729.206	1413.84	1146.58	1410	2646	2043	1610	
Aluminum (mg/kg)	2463.02	3631.21	311.2	3309.16	3872.52	5556.41	4496.53	4646.16	
Iron (mg/kg)	2501.11	2841.64	2901.24	2971.81	3932.41	4348.22	4193.09	4172.5	
Manganese (mg/kg)	131.19	101.88	129.98	103.6	206.26	155.9	187.86	145.46	
Copper (mg/kg)	12.142	10.284	12.315	11.955	19.09	15.74	17.8	16.78	
Zinc	31.17	40.05	41.51	42.11	49.01	61.29	59.99	59.13	

Conclusions

- Sargassum can be used to create a quality compost.
- Salinity not an issue.
- Presence of sand attributes to high solids %, low moisture and low organic matter.
  - Can be good for drainage
- Composting Sargassum requires additional nitrogen inputs such as food waste, fish waste or manure.



Thank You!
Any Questions?

Contact:
tc10@txstate.edu

Examining the Quality of a Compost Product Derived from Sargassum

Kevin T. Walsh[1] and Tina M. Waliczek[1]

ADDITIONAL INDEX WORDS. **aquatic plant management, beach management, brown algae, brown seaweed, exotic, invasive species, *Sargassum fluitans*, *Sargassum natans*, seaweed, soil ecology, waste management**

SUMMARY. **The free-floating algae known as sargassum (*Sargassum fluitans* and *Sargassum natans*) drifts onto coastlines throughout the Atlantic Ocean during spring and summer months. Beach communities seek to maintain tourist appeal and, therefore, remove or relocate the sargassum drifts once it collects on shore. Maintenance efforts have attempted to incorporate the sargassum into dunes and beach sand. However, not all communities have the resources to manage the biomass and must dispose of it in a landfill. The utility of the seaweed biomass as a fertilizer for plant growth has been renowned for centuries. The purpose of this project was to evaluate the appropriate proportion of sargassum for other compost ingredients used in a large-scale composting system to create a quality product for utilization in horticultural and/or agricultural products. This study used ≈32 yard³ of sargassum as part of 96 yard³ of compost material that also included food waste, fish waste, and wood chips. Four protocols were prepared and included either 25% or 41.5% sargassum and various proportions of food or fish waste and wood chips, which are ingredients that would be readily available in coastline communities, to determine the ideal ratios of materials to create a quality compost. Piles were turned regularly and monitored for pH, moisture, and temperatures according to compost industry standards and approximately every 5 to 7 days. Piles cured for 4 to 8 weeks and the entire composting process lasted 5 months. Samples of compost were collected and tested through the Agricultural Analytical Services Laboratory's U.S. Composting Council's Seal of Testing Approval Program at Pennsylvania State University. All final compost products and protocols had reasonable quality similar to those required by current compost standards. However, the protocol incorporating equal parts sargassum (41.5%) and wood chips (41.5%), fish waste (4%), and food waste (13%) had the best results in terms of organic matter content and overall nutrient levels. Therefore, this study determined that waste management industries can use sargassum as a feedstock through a large-scale composting system to create a desirable compost product that could be used in the horticulture industries. Sargassum could also be composted and then returned to the shoreline, where it would help build soils and vegetation.**

The Sargasso Sea was once a place of frightening legends to sailors of centuries ago, known as a windless and gnarly trap of a distinct flora that shrouded the mysterious waters, hiding alien monsters within its dark waters (Genthe, 1998). Contained by the Atlantic gyre, the Sargasso Sea exists as a unique anomaly because it is the only sea on earth without a coastline. When comparing the entire Atlantic gyre to a tropical storm system, the Sargasso Sea would be the "eye" of the vortex, with calm and still waters (Genthe, 1998). The ocean currents contain the warm waters of the Sargasso Sea like a shallow bowl that is still being sculpted. As life grows inside this bowl and branches out, the ocean currents randomly distribute flora and fauna alike toward the coastlines throughout the Atlantic Ocean, most commonly in southern Europe, North America, and the Caribbean (Righton et al., 2016).

Sargassum is a planktonic species of macroalgae [Phaeophyceae (Wang et al., 2009)]. These free-floating organisms reach a seasonal peak in growth and mass each year and will typically reach the Texas coast during the summer months (Round, 1981). When the sargassum touches the shoreline, it forms "mats" that pile up to recorded heights of 4 ft and stretch several hundred yards (Williams and Feagin, 2010). Then, the sargassum begins to decay and releases its fish and crustacean passengers like tourists exiting a cruise ship. Incidentally, actual tourists are attracted to the beach during the same summer months. As the number of beachgoers increases, the more inconvenient a mat of sargassum becomes to maintain tourist appeal (Williams and Feagin, 2010). Additionally, with warming temperatures in the oceans and increased urbanization leading to excess amounts of runoff of fertilizers into waterways, sargassum blooms have become more intense worldwide and are predicted to continue being a problem for coastal communities (Akin, 2019).

Many beach communities employ efforts to physically remove the sargassum. Using front-end loaders, the biomass can be raked or shoveled and often relocated along foredunes, where it can continue to naturally decompose. Another method involves spreading the sargassum evenly along the shore and covering it with sand, thereby rebuilding the shore rather than the dunes (M. Smith, personal communication). However, due to either local attitudes or limitations in maintenance, not all communities are able to adopt these methods and will take the more convenient

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[1]Department of Agricultural Sciences, Texas State University, 601 University Drive, San Marcos, TX 78666

K.T.W. is a Graduate student.

T.M.W. is a Professor of Horticulture.

T.M.W. is the corresponding author. E-mail: tc10@txstate.edu.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
1	mmho/cm	$dS \cdot m^{-1}$	1
1	ppm	$mg \cdot kg^{-1}$	1
0.7646	yard³	m³	1.3080
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

option of having the sargassum removed entirely and disposed in a landfill (Akin, 2019).

There remains much debate regarding the matter of removing sargassum. When tourists of Matagorda Island, TX, were surveyed, 63.89% of participants disagreed with the statement, "seaweed should be removed from the beach completely" (Williams, 2010). The City of Galveston, TX has recently launched a public education campaign to encourage beachgoers to embrace the seaweed and public opinions are beginning to view the biomass as less of a nuisance compared with past views (Rice, 2015).

The utility of the seaweed biomass as a fertilizer for plant growth has been renowned for centuries (Panda and Nayak, 2012; Verkleij, 1992). Algae species such as norwegian kelp or rockweed (*Ascophyllum nodosum*) are used as a reliable source of plant nutrients in agricultural applications (Eyras et al., 2008; Win and Saing, 2008). Sargassum itself works as a natural fertilizer for coastal flora along the Texas coast, and its use is advocated for the restorative maintenance of dune ecology after hurricanes (Williams, 2010).

Recent research has shown positive results of sargassum used as a feedstock in large-scale composting to produce organic soil amendments, such as compost (Eyras et al., 2008; Sembera et al., 2018). Limitations and methods of the previous study included incorporating a low percentage of sargassum biomass (Sembera et al., 2018). The past study did not reflect the extremes of sargassum accumulation that coastal beaches might experience (Sembera et al., 2018). Neither did this previous study examine the potentially high concentrations of salt when incorporating greater proportions of material, which could have undesirable results on the finished compost product (Illera-Vives et al., 2015; Sembera et al., 2018).

Composting is the natural process of breaking down organic matter into a usable, waste-free product, and it is increasingly used as a waste management system (Sanders et al., 2011). Compost products are valuable commodities to agricultural, horticultural, and related users (Rynk, 1992; Walker et al., 2006). During the active stage of composting, bacteria and other microorganisms consume oxygen and release carbon dioxide, thus producing a large amount of heat (Rynk, 1992). Temperatures must reach higher than 57 °C to kill pathogens as well as plant propagules or seeds (Dougherty, 1999). Finished compost can process down to 50% or less of the original volume of raw material (Rynk, 1992), thus making it an effective means of waste management (Day and Shaw, 2001).

In addition to horticulture, compost is used in other agricultural operations. Amended into soil, compost boosts soil fertility and improves soil structure while increasing the water-holding capacity and decreasing runoff (Rynk, 1992). Compost is known to increase the number and diversity of microorganisms and to enhance beneficial chemical and physical properties of the soil, which helps plants develop natural immunities to diseases, insects, and parasites (Reardon and Wuest, 2016). This process is promoted by carbon-based materials that slowly release nitrogen, phosphorus, and potassium into the soil over time (Dougherty, 1999; Rynk, 1992).

This project first examined the large-scale compost management of sargassum as a method that could potentially be replicated near the regional communities burdened by the plant. Then, it investigated the limits of a compost management system when using sargassum as a feedstock to create a marketable product for utilization in horticulture and related industries. Therefore, the purpose of this project was to evaluate the appropriate proportion of sargassum for other compost ingredients used in a large-scale composting system to create a quality product for utilization in horticultural and/or agricultural products.

Materials and methods

Material collection. Sargassum biomass was collected from the shoreline at Mustang Island State Park in Texas by a front-end loader and placed into vehicles for transportation. Supervision of the removal and collection of the sargassum biomass was managed by the City of Corpus Christi Parks and Recreation Department according to the permit established by the U.S. Corps of Engineers and the City of Corpus Christi Beach adaptive management plan. Additional supervision by the Turtle Patrol, overseen by Texas Parks and Wildlife Department ensured that habitat of the kemp's ridley sea turtle (*Lepidochelys kempii*) was not disturbed.

Approximately 80 yards^3 of "fresh" sargassum (sargassum biomass that arrived on the shoreline during the previous 24 h) were harvested for the study. Significant dry-down occurred immediately after harvesting due to natural processes after it was removed from its saline, aquatic environment, thus altering the biomass to ≈50% less volume compared with the original amount harvested.

Compost pile creation and management. Compost piles were created on a 5-acre plot of land. Approximately 2.5 acres were allocated for the compost site and the other 2.5 acres surrounding the compost site served as runoff space and a catchment pond that could withstand a 25-year 24-h flooding event (Meier et al., 2014).

Piles were turned regularly to mix ingredients and aerate them. They were monitored according to compost industry standards approximately every 5 to 7 d (Dougherty, 1999) using a procedure involving five measurements obtained from sample locations in the pile and averaged to ensure the following ideals were reached: pH between 5.5 and 9.0 (Soil pH Tester; Kel Instruments Co., Wyckoff, NJ); moisture content between 40% and 65% (24-inch Moisture Meter; Lincoln Irrigation, Lincoln NE); and temperatures above 62 °C for a minimum of 3 d (60-inch Compost Thermometer Probe; ReoTemp Instrument Co., San Diego, CA) (Dougherty, 1999).

The entire composting process lasted 5 months. When active composting was completed, regular turning and irrigation were halted and piles were allowed to cure for 4 to 8 weeks (Dougherty, 1999; Rynk, 1992). Although food waste and wood chips are acidic feedstocks within compost, seaweed is slightly alkaline (Cooperband, 2002; Darlington, 2007; Dougherty, 1999; Maze et al., 1993). Compost research has indicated that piles allowed to cure for 3 to 4 months tend to have lower pH values (Dougherty, 1999). Therefore, curing piles for more than 1 month could allow the compost more time to become more acidic if deemed necessary.

Compost pile protocols and treatments. Compost requires proper ratios of nitrogen and carbon sources (Rynk, 1992). During this research study, university cafeteria food waste (including vegetable, meat, dairy, and bread) was used as the primary nitrogen source. Invasive fish species plecostomus (*Hypostomus plecostomus*) and tilapia (*Oreochromis* sp.) were collected and included as an additional nitrogen source in the compost piles as part of ongoing invasive species removal from the San Marcos River, as contracted by the City of San Marcos, TX. Wood chips produced and donated by a local tree care company and leaf litter from the university campus were used as the primary carbon inputs and as a bulking agent to promote airflow through the compost piles. A previous study included sargassum in the compost protocols at an amount of 2% and did not reflect the extremes of sargassum accumulation that coastal beaches might experience (Sembera et al., 2018). Therefore, the compost protocols for this study included proportions of 25% and 41.5% sargassum. A total of 31.8 yard^3 of sargassum was used for the project.

Each of the four protocols were replicated three times and placed into piles containing 8 yard^3 feedstocks per pile (Table 1). Protocol A included 17% food waste (1.4 yard^3), 41.5% wood chips (3.3 yard^3), and 41.5% sargassum (3.3 yard^3). Protocol B included 13% food waste (1 yard^3), 41.5% wood chips (3.3 yard^3), 41.5% sargassum (3.3 yard^3), and 4% fish waste (0.4 yard^3). Protocol C included 21% food waste (1.6 yard^3), 50% wood chips (4 yard^3), 25% sargassum (2 yard^3), and 4% fish waste (0.4 yard^3). Protocol D included 25% food waste (2 yard^3), 50% wood chips (4 yard^3), and 25% sargassum (2 yard^3). A total of 12 piles that were 6 ft in height and 8 ft in diameter were created, with the total amount of feedstocks equaling 96 yard^3. The four protocols each had a total of 24 yard^3 of material.

Compost quality tests. After curing, samples were taken from the compost. It was noted during sampling that fish scales were present in the two protocols using fish waste and that a significant amount of beach sand was present in the final screened product of all four protocols.

Sampling techniques adhered to the collection procedures specified by the Agricultural Analytical Services Laboratory at Pennsylvania State University (2016). For each test, subsamples from each compost pile were collected from three different depths at five locations. These 15 subsamples were combined to create four 0.5-gal composite samples representative of each pile; then, subsamples were sent to the Agricultural Analytical Services Laboratory's U.S. Composting Council's Seal of Testing Approval (STA) Program at Pennsylvania State University (University Park). These are the current standards that the industry uses to gauge whether compost is suitable to market. The samples were evaluated based on the following characteristics: pH, soluble salt content or electrical conductivity (EC), moisture content, organic matter content, total nitrogen, total carbon, carbon-to-nitrogen ratio, phosphorus, potassium, calcium, magnesium, and metals (aluminum, copper, and zinc). Bioassay tests were also conducted to observe maturity and stability measurements of compost samples (Meier et al., 2014; Montoya et al., 2013; Pennsylvania State University, 2016; U.S. Composting Council, 2002).

Data analysis. Frequencies and descriptive data were reported for each protocol regarding compost quality standard attributes. An independent *t* test was conducted using SPSS (version 20.0; IBM Corp., Armonk, NY) to statistically compare results from each of the four compost protocols ($P < 0.05$). Because the study was limited to one sample and one data point per variable per protocol, *t*-tests were used.

Results and discussion

A total of ≈20 yard^3 of stabilized compost was created. All protocols exhibited results within the normal range of quality compost. The finished product created from the used waste materials was valued at approximately \$45/yard^3 or \$900 on the local market (Garden-Ville, unpublished data).

Compost quality test results. Results of the compost quality tests indicated that pH, soluble salt content, total nitrogen, total carbon, carbon-to-nitrogen ratio, particle size, and bioassay measurements of all samples regardless of the protocol were within normal to ideal ranges for compost typically sold in the horticultural industry (Table 2). Additionally, metal content did not exceed normal ranges.

Notably, the recorded levels of soluble salts indicated that salinity was not an issue when using sargassum as a primary feedstock (Table 2). The analyses identified the final compost product in all protocols as having a soluble salt content ranging from 2.92 to 4.2 mmho/cm and was well

Table 1. Compost protocol percentages and total yard^3 per pile of feedstocks used to evaluate the appropriate proportion of sargassum for other compost ingredients to be used in a large-scale composting system.

Protocol group	Food waste	Wood chips	Sargassum	Fish waste	Piles (no.) and volume (yard^3)^z
A	17%	41.5%	41.5%	—	3
Amount (yard^3)^z	1.4	3.3	3.3	—	8
B	13%	41.5%	41.5%	4%	3
Amount (yard^3)	1	3.3	3.3	0.4	8
C	21%	50%	25%	4%	3
Amount (yard^3)	1.6	4	4	0.4	8
D	25%	50%	25%	—	3
Amount (yard^3)	2	4	4	—	8

^{z}1 yard^3 = 0.7646 m^3.

Table 2. Independent *t*-test comparisons of results of compost quality of protocols A, B, C, and D to evaluate the appropriate proportion of sargassum for other compost ingredients to be used in a large-scale composting system.

Variable (units)[z]	Protocol A results	Protocol B results	Protocol C results	Protocol D results	Normal range (USCC)[y]	*t*	df	*P*
pH	7.3	7.3	7.8	7.2	5.0–8.5	54.653	3	<0.001*
Soluble salts (mmho/cm)	2.92	4.2	3.87	3.01	1–10	11.052	3	0.002*
Solids (%)	63.6	65.4	69.2	71.2	50–60	38.825	3	<0.001*
Moisture (%)	36.4	34.6	30.8	28.8	40–50	16.987	3	<0.001*
Organic matter (%)	21.6	36.4	25.9	21.7	30–70 (dry weight)	8.049	3	0.004*
Total nitrogen (%)	0.84	1.56	1.16	1.06	0.5–2.5 (dry weight)	7.807	3	0.004*
Carbon (%)	12.6	23.6	15.4	14.7	<54 (dry weight)	7.2	3	0.006*
Carbon:nitrogen (ratio)	13.2	15.1	13.2	13.9	<20 (dry weight)	31.33	3	<0.001*
Phosphorus (%)	0.471	0.842	0.797	0.864	—	7.22	3	0.005*
Potassium (%)	0.35	0.49	0.45	0.43	—	12.844	3	0.001*
Calcium (%)	12.02	18.66	14.37	12.22	—	9.837	3	0.002*
Magnesium (%)	0.4	0.46	0.4	0.33	—	16.979	3	<0.001*
Sulfur (%)	0.18	0.23	0.21	0.18	—	15.545	3	0.001*
Sodium ($mg \cdot kg^{-1}$)	1,410	2,646	2,043	1,610	—	7.257	3	<0.001*
Aluminum ($mg \cdot kg^{-1}$)	3,872.52	5,556.41	4,496.53	4,646.16	—	12.698	3	0.001*
Iron ($mg \cdot kg^{-1}$)	3,932.41	4,348.22	4,193.09	4,172.5	—	26.860	3	<0.001*
Manganese ($mg \cdot kg^{-1}$)	206.26	155.9	187.86	145.46	—	14.493	3	0.001*
Copper ($mg \cdot kg^{-1}$)	19.09	15.74	17.8	16.78	—	24.884	3	<0.001*
Zinc ($mg \cdot kg^{-1}$)	49.01	61.29	59.99	59.13	—	15.179	3	0.001*
Bioassay: emergence (% of control)	100	100	100	100	>90 (very mature)	—	—	—
Bioassay: seedling vigor (%)	100	100	100	100	>95 (very mature)	—	—	—

[z]The variables of pH, soluble salts solids and moisture, bioassay (% of control) and bioassay (seedling vigor) were each measured on a fresh weight basis, while the remaining variables were reported from dry weight analysis; 1 mmho/cm = 1 $dS \cdot m^{-1}$; 1 $mg \cdot kg^{-1}$ = 1 ppm.
[y]U.S. Composting Council (2002).
*Statistically significant at $P < 0.05$.

within the acceptable range of 1.0 to 10.0 mmho/cm (Pennsylvania State University, 2016). Although the levels found in this study were safe based on compost quality standards, there was a notable increase in the soluble salt content compared to that of a previous study of composting sargassum that had detected a range of 1.10 to 1.59 mmho/cm in soluble salts (Sembera et al., 2018). The increase in soluble salt content in the current study was likely due to the increased proportions of sargassum biomass incorporated.

During the collection process of the sargassum biomass, the front-end loader inadvertently collected beach sand along with the biomass. The beach sand became mixed with the sargassum during the loading procedure before being transported to the university compost site. The sand was not removed; instead, it was incorporated in the compost piles with the biomass. The characteristics of sand are reflected in the percentage of solids, moisture, and organic matter. The percentage of solids for the overall substrate ranged from 63.6% to 71.2%, which were outside the recommended levels of 50% to 60% (Pennsylvania State University, 2016). The percentages of moisture were below normal values (40% to 50%) and ranged from 28.8% to 36.4% in all protocols (Table 2). Three of the four treatments exhibited lower than normal percentages of organic matter. Noting these qualities, this sargassum-incorporated compost product would provide slightly less organic matter while potentially providing improved drainage and aeration in a "landscape mix" type of application and/or would be well-suited for clay-heavy soils (Rynk, 1992). Bioassay tests concluded that all measurements of compost samples were identified at 100%, ensuring the maturity and stability of the compost product (Pennsylvania State University, 2016; Sembera et al., 2018; U.S. Composting Council, 2002).

Statistical comparisons of compost protocols. Results of independent *t* tests indicated significant differences between compost quality parameters. Protocol A incorporated the greatest amount of sargassum (≈41.5%), which was equal to the percentage of wood chips. The only nitrogen-rich feedstock in this protocol was food waste (≈17%), and the protocol included no invasive fish species waste. Of the four protocols, protocol A produced the least desirable results for a quality compost product. Although all results for protocol A were within quality compost standards, the results for total nitrogen (0.84% dry weight), carbon (12.6% dry weight), phosphorus (0.471% dry weight), and potassium (0.35% dry weight) were the numerically lowest of all the protocols. Additionally, the results of secondary macronutrients (i.e., calcium, magnesium, and sulfur) and many of the micronutrients (i.e., iron and zinc) were the numerically lowest of all protocols. However, protocol A had the greatest amount of manganese (206.26 $mg \cdot kg^{-1}$ dry weight) and the second greatest amount of copper (19.09 $mg \cdot kg^{-1}$ dry weight) (Table 2).

Protocol B produced the most desirable results of the four protocols. This protocol mirrored the proportions of sargassum (41.5%) and wood chips (41.5%) within protocol A. However, the inclusion of fish waste (4%) required a smaller amount of food waste (13%) compared with protocol A. Although the percentages of solids and moisture were higher and lower, respectively, when compared with normal ranges of compost quality standards, protocol B was the only protocol in the study to exhibit an organic matter percentage within the normal range (P = 0.004). Protocol B had the highest concentrations of total nitrogen (1.56% dry weight), carbon (23.6% dry weight), and potassium (0.49% dry weight) of the four protocols, and the second numerically highest percentage of phosphorus (0.842% dry weight). Results for protocol B also showed higher concentrations of many secondary nutrients and micronutrients, with some notable exceptions. The results for sulfur (0.23% dry weight) and iron (4348.22 $mg \cdot kg^{-1}$ dry weight) were similar to the results of protocol C, which had a slightly lower sulfur content (0.21% dry weight) and slightly greater iron content (4193.09 $mg \cdot kg^{-1}$ dry weight), indicating a common trait between the two compost protocols that incorporated fish waste. Protocol B had the greatest concentration of calcium (18.66% dry weight) and had significantly greater results (P = 0.002) than the other three protocols (Table 2).

Protocol C incorporated a lower percentage of sargassum (≈25%) in contrast to protocols A and B, and it included fish waste (4%). This protocol exhibited percentages of moisture and organic matter that were numerically lower than the ideal quality compost range. The concentrations of total nitrogen (1.16% dry weight), carbon (15.4% dry weight), phosphorus (0.797% dry weight), and potassium (0.45% dry weight) were numerically lower than those of protocol B, but they were still within normal ranges of a quality compost product. This protocol achieved the second highest results regarding macronutrients such as nitrogen, phosphorus, and potassium (Table 2), the second highest amount of manganese (187.86 $mg \cdot kg^{-1}$ dry weight) and the greatest amount of copper (17.8 $mg \cdot kg^{-1}$ dry weight).

Protocol D mirrored the amount of wood chips (50%) and sargassum (25%) as those used in protocol C. Food waste (25%) was used to provide nitrogen. The quality test results were within the normal compost quality standards, but their percentages of macronutrients were not as high as those of protocol B and protocol C (Table 2). Again, the presence of sand incorporated from the beach harvest of sargassum increased the percent of solids and decreased moisture and organic matter compared with those of normal quality compost standards. However, the concentrations of total nitrogen (1.06% dry weight), carbon [14.7% dry weight (P = 0.006)], phosphorus [0.864% dry weight (P = 0.005)] and potassium [0.43% dry weight (P = 0.001)] were at ideal compost quality levels and significantly higher when compared with those of protocol A (Table 2).

All samples of the four protocols had salt content, pH, and nutrient levels within the normal quality compost standards, as well as successful bioassay results (Table 2). Noting the greater percentages of organic matter in the quality reports of protocols B and C, it is apparent that sargassum should be balanced with appropriate nitrogen-supplying feedstocks, such as food waste or fish waste. Fish waste improved the quality of compost, as was observed in comparisons of protocol A and protocol B. However, increasing the proportion of other nitrogen-rich feedstocks could also improve the quality of a sargassum-heavy compost protocol, as shown in protocol D when compared with protocol A. Although the statistical analysis showed a significant difference in the pH values of the four protocols, the range of pH values (7.2–7.8) in regard to horticultural practices would be generally acceptable. Additionally, over time, compost tends to become more acidic (Rynk, 1992). Although it was determined that all protocols met most of the quality compost product standards, the results of protocol B were the most desirable due to the presence of significantly higher organic matter (P = 0.004) and generally higher levels of nutrients.

Future studies like this one should include collecting additional samples to include more data points during statistical analyses. Furthermore, future studies should include a marketing analysis of the compost product as a boutique compost or soil blend and refine the protocols to achieve the most beneficial results. Additionally, as recommended in a previous study, a cost-benefit analysis of the removal of sargassum would be instructive for the communities impacted by sargassum. Comparisons of the various disposal methods, composting, landfilling, or dune maintenance would provide additional information for beach communities, thus allowing them to make informed decisions regarding approaches to beach maintenance (Sembera et al., 2018).

There remains concern for coastal ecology. Although this study provided evidence that sargassum is a suitable feedstock for composting and can be incorporated into compost piles at high proportions, when evaluating how to manage sargassum drifts, it should be noted that coastal flora benefit greatly from them (Rice, 2015). Management practices should exercise efforts to incorporate the sargassum biomass into the beach, either by building foredunes or by raking the biomass into the shore. Compost created from sargassum could also be returned to the coastline. The process of composting can be used to appropriately decompose the biomass in large amounts and assist the Gulf Coast region with moving toward zero-waste goals.

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Preliminary and Regional Reports

Composting as an Alternative Management Strategy for Sargassum Drifts on Coastlines

Jen A. Sembera[1], Erica J. Meier[1], and Tina M. Waliczek[2,3]

ADDITIONAL INDEX WORDS. **aquatic plant management, beach management, compost, compost quality, exotic, invasive species, *Sargassum fluitans*, *Sargassum natans*, brown algae, seaweed**

SUMMARY. **Massive drifts of sargassum (*Sargassum fluitans* and *Sargassum natans*) float onto the United States Gulf, Atlantic, and European shorelines regularly throughout the spring and summer months. To maintain tourist appeal and subsequently, the tourism industry, the standard practice of Texas beach communities has been to mechanically remove the sargassum seaweed and integrate it into dunes along the shoreline or dispose of the material in the landfill. The purpose of this study was to evaluate the potential to manage the invasive species sargassum using composting and to test the quality of the resulting compost. This study used ≈12 yard³ of sargassum as a feedstock mixed with cafeteria food waste and local wood chips, using a total of ≈72 yard³ of feedstocks, to create nearly 25 yard³ of stabilized compost. The final compost products were of equal or higher quality to current compost standards. Therefore, this study determined that the composting and waste management industries can use sargassum as a feedstock to create a desirable compost product that could be used in the horticulture and agriculture industries, while helping to manage this invasive species.**

Nearly 10,000 different types of seaweed algae thrive in the world's oceans and seas (Abbott and Dawson, 1978; Fritsch, 1965). Algae in the genus *Sargassum* of the sargassum family (Sargassaceae) include more than 150 species distributed throughout the tropical and temperate oceans around the world, thriving in warmer oceans and seas (Abbott and Dawson, 1978; Fritsch, 1965). Two planktonic species (*S. fluitans* and *S. natans*) drift en masse onto the shores of the Texas Gulf Coast, and are known collectively as brown algae, gulfweed, seaweed, sea holly, or sargassum. Sargassum that "washes" to shore can accumulate into massive, troublesome mounds, which substantially affects local coastal economies that rely on the beaches associated with the local tourism industry (Gaskill, 2015; Texas General Land Office, 2007). Sargassum was added to the Global Invasive Species Database in 2011 (Invasive Species Specialist Group, 2011) and has been identified along the shorelines of North America, Central America, the Caribbean Islands, the western Atlantic, Southwest Asia, and Southeast Asia (Guiry and Guiry, 2013).

Free-floating species of sargassum reproduce asexually by fragmentation (Awasthi, 2005; Rogers, 2011). Both require warmer oceans and sea temperatures to thrive, as well as chemical properties in their aquatic environment to survive (Abbott and Dawson, 1978; Fritsch, 1965; Round, 1981). Sargassum decreases in size after landing on the shore, and within a 5-d period, the seaweed decreases about three times in volume, becomes brittle, and changes from a light yellow to dark brown color (Round, 1981).

Nutrients absorbed from the sea, in combination with the energy from the sun, make seaweed rich in major nutrients and trace nutrients, and these nutrients can be used as soil amendments and fertilizers (Verkleij, 1992). Williams and Feagin (2010) studied the application of sargassum on native coastal plants beach sunflower (*Helianthus debilis*), fiddle-leaf morning glory (*Ipomoea stolonifora*), bitter panicgrass (*Panicum amarum*), seashore dropseed (*Sporobolus virginicus*), and seaside oats (*Uniola paniculata*) as a natural solution to enhance native dune plant growth. The study found sargassum acted as a natural fertilizer for bitter panicgrass (Williams and Feagin, 2010). Another study (Verkleij, 1992) found adding a seaweed-based soil amendment supplemented nutrient-poor sandy soils (Verkleij, 1992). In addition, some biological agriculture and horticulture practices have applied diluted seaweed extracts to enhance growth, deter insects and diseases, and improve quality of harvests (Verkleij, 1992).

Department of Agriculture, Texas State University, 601 University Drive, San Marcos, TX 78666

[1]Graduate Student.

[2]Professor of Horticulture.

[3]Corresponding author. E-mail: tc10@txstate.edu.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
1	mmho/cm	$dS\cdot m^{-1}$	1
0.001	ppm	$mg\cdot g^{-1}$	1,000
1	ppm	$mg\cdot kg^{-1}$	1
0.7646	yard³	m³	1.3080
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Beaches along the Texas coastline are maintained by various organizations including federal and state agencies, cities, counties, and private owners (Gaskill, 2015; Texas General Land Office, 2007; Williams and Feagin, 2007). Variations of management procedures and methods are used by these organizations; however, basic beach maintenance objectives include maintaining safe and sanitary conditions, allowing for the use of recreational activities (e.g., sunbathing, camping, wildlife observation, and beach combing), monitoring trash removal, protecting wildlife habitats, and limiting the amount of sargassum on the coastline (Williams and Feagin, 2007).

The sargassum on beaches is handled using a variety of methods; if small amounts of biomass float onto the shore, large rakers are used to remove it. For large amounts, front-end loaders are allowed access to the shoreline to scrape tons of sargassum and sand, where it is then either placed at the edge of the foredune and allowed to revegetate or placed in temporary holding centers (Williams and Feagin, 2010). This method is used to create "maintenance dunes" seaward of the natural dunes (Gaskill, 2015).

Raking is only implemented during the 4–6 months of the year when the mats of sargassum rest on the shore. A large concern of some property owners and cities is that the peak times of sargassum deposits overlap with peak tourist seasons. Tourists often expect pristine beaches free from any debris and view seaweed mats as poor beach maintenance (Gaskill, 2015). In local economies that are highly dependent on tourism dollars, maintaining or increasing tourist numbers is essential (Gaskill, 2015; Texas General Land Office, 2007).

Although sargassum are used to create stabilized maintenance dunes, many coastal areas are running out of beach space because of rising sea levels, erosion, and the increasing size of these dunes (Williams et al., 2015). Even though wider dunes allow more protection from strong storms and increased native vegetation, the public demands and expects fast and easy access to the beach, and view these wider dunes or "long walks" as impeding beach enjoyment (Williams et al., 2015).

Composting is a biomechanical process during which microorganisms such as bacteria and fungi convert organic matter (OM) and "waste" materials into a soil-like product called compost (Rynk, 1992). The addition of compost to soil provides various benefits including increasing soil fertility, improving soil structure, increasing water holding capacity, and decreasing runoff (Dougherty, 1999; Rynk, 1992). Composting is increasingly used as a waste management method, a technique for pollution diversion, and to produce a valuable commodity for agricultural, horticultural, and related users (Walker et al., 2006).

Compost created from saline feedstocks (e.g., oceanic algae) must be carefully controlled and monitored for proper electrical conductivity (EC) amounts (Vendrame and Klock-Moore, 2013). Previous studies have used irrigation to wash away the soluble salt content before or during the compost process. Eyras et al. (1998) showed that time also plays a role: compost containing high-salinity feedstock aged for 20 months contained dramatically lower amounts of salt than compost aged for 9 months. Feedstocks of high salinity also can be combined with low salinity feedstocks to dilute the final product. Finally, actively turning the piles (rather than leaving them static) was shown to increase the rate of compost creation while decreasing the level of salinity (Eyras et al., 1998).

Seaweed extracts that contained different plant phytohormones and growth regulators increased crop yields when they were applied exogenously (Panda and Nayak, 2012). Some biological agriculture and horticulture practices have used diluted seaweed extracts or "seaweed fertilizers" to "promote growth, prevent pests and disease, and improve the quality of the products" (Verkleij, 1992). Therefore, producing compost that uses seaweed as a feedstock has the potential to create a nutrient-rich soil amendment product (Klock-Moore, 2000; Panda and Nayak, 2012).

The purpose of this study was to evaluate the potential to manage the invasive species sargassum using composting and to test the quality of the resulting compost.

Materials and methods

Material collection. Removal of sargassum biomass from the shoreline and placement into vehicles for transportation was supervised by the City of Corpus Christi, TX, according to the permit established by the U.S. Army Corps of Engineers and the City of Corpus Christi Beach Adaptive Management Plan (City of Corpus Christi, 2011). Over the span of 2 d, a total of ≈18 yard^3 of "fresh" sargassum (seaweed that arrived on the shoreline during the previous 24 h) was collected by employees of the City of Corpus Christi to ensure proper procedures were followed. Similar biomass amounts were harvested in related projects studying composting as a management system for invasive species (Meier et al., 2014; Montoya et al., 2013). Within 5 d, the sargassum biomass had shrunk to 2 yard^3.

Compost pile recipes and treatments. Half of the sargassum harvest was manually washed with tap water and screened through a charcoal fiberglass screen wire to remove as much tar, salt, and sand as possible. The other half of the sargassum was left alone. Tap water used in washing the sargassum contained typical elements such as chlorine and fluoride that could affect the results in comparisons and was a limitation in the study.

A total of six piles 6 ft in height and 10 ft in diameter were created. Washed and unwashed sargassum piles each received ≈6 yard^3 (48%) of food waste generated from the kitchen cafeterias at Texas State University (San Marcos), 6 yard^3 (48%) of wood chips produced and donated by a local tree-care company, and 1/2 yard^3 (4%) of sargassum, respectively, and were replicated three times. No true control pile of compost was necessary as in compost quality tests, compost samples are compared with overall compost quality standards for the industry (U.S. Composting Council, 2002).

Compost pile creation and management. Compost piles were created on a 5-acre plot of land. About 2.5 acres were allocated for the compost site and the other 2.5 acres surrounding the compost site served as runoff space and a catchment pond that could withstand a 25-year, 24-h flooding event (Meier et al., 2014).

Every 5–7 d, piles were turned regularly and monitored given compost industry standards (Dougherty, 1999). Readings were taken from five areas within each pile and averaged to ensure the following ideals were reached: pH between 5.5 and 9.0 (Soil pH direct reading sensor; Kelway, Wyckoff, NJ), moisture content between 40%

and 65%, and temperatures greater than 62 °C for a minimum of 3 d (Super Duty-Fast Response Windrow Compost Thermometer; Reotemp Instrument Corp., San Diego, CA). A minimum temperature of 62 °C was chosen as the ideal temperature to achieve during the composting process to kill pathogens (Meier et al., 2014; Montoya et al., 2013). After the active composting phase, piles were allowed to cure for at least 4 weeks to complete the composting process (Dougherty, 1999; Rynk, 1992).

COMPOST QUALITY TESTS. After curing, samples were drawn from the compost. Sampling techniques adhered to the collection procedures specified by the Agricultural Analytical Services Laboratory at Pennsylvania State University (2002). For each test, subsamples from each compost pile were collected from three different depths at five locations. These 15 subsamples were combined to create four 0.5-gal composite samples representative of each pile which were then sent to the Agricultural Analytical Services Laboratory's U.S. Composting Council's Seal of Testing Approval Program at Pennsylvania State University (University Park). The samples were evaluated on the following characteristics: pH, soluble salt content or EC, moisture content, OM content, total nitrogen, total carbon, carbon:nitrogen ratio, phosphorus, potassium, calcium, magnesium, particle size, and metals arsenic, cadmium, copper, lead, mercury, molybydenum, nickel, selenium, and zinc. Respirometry and bioassay tests were also conducted to observe maturity and stability measurements of compost samples (Meier et al., 2014; Montoya et al., 2013; Pennsylvania State University, 2002; U.S. Composting Council, 2002).

DATA ANALYSIS. Frequencies and descriptive data were reported at each stage of the project. An independent t test was conducted using SPSS® (version 20.0; IBM Corp., Armonk, NY) to statistically compare results from the washed and unwashed sargassum.

Results and discussion

In total, 25 yard^3 of stabilized compost was created. This bulk product, created from waste materials, was valued at $900 on the local market

Table 1. Independent t test comparisons of results of moisture included and dry weight compost quality of washed and unwashed sargassum in the study of composting as an alternative management strategy for sargassum drifts on coastlines.

Variable (units)[z]	Washed sargassum (as is basis)[y]	Washed sargassum (dry wt basis)[y]	Unwashed sargassum (as is basis)	Unwashed sargassum (dry wt basis)	Normal range (USCC)[x]	t	df	P
pH	8.4	—	8.1	—	5.0–8.5	55.000	1	0.012*
Soluble salts (mmho/cm)	1.14	—	1.59	—	1–10	6.067	1	0.104
Solids (%)	57.8	—	74.7	—	50–60	7.840	1	0.081
Moisture (%)	42.2	—	25.3	—	40–50	3.994	1	0.156
Organic matter (%)	21	36.3	23	30.8	30–70 (dry weight)	22.000	1	0.029*
Total nitrogen (%)	0.8	1.4	1.0	1.3	0.5–2.5 (dry weight)	9.000	1	0.700
Carbon (%)	10.8	18.7	13.4	18	<54 (dry weight)	9.308	1	0.068
Carbon:nitrogen (ratio)	13.5	13.5	13.4	13.4	<20 (dry weight)	269.00	1	0.002*
Phosphorus (%)	0.36	0.61	0.36	0.48	—	—	0	—
Potassium (%)	0.41	0.71	0.45	0.60	—	21.500	1	0.030*
Calcium (%)	3.5	6.06	4.83	6.46	—	6.263	1	0.101
Magnesium (%)	0.24	0.41	0.28	0.37	—	13.000	1	0.049*
Arsenic (mg·kg^{-1})	4.2	7.2	4.4	5.9	<75	43.000	1	0.015*
Cadmium (mg·kg^{-1})	<0.3	<0.5	<0.3	<0.5	<85	—	0	—
Copper (mg·kg^{-1})	10.7	18.6	10.3	13.7	<4,300	52.500	1	0.012*
Lead (mg·kg^{-1})	3.8	6.5	4.9	6.5	<420	7.909	1	0.080
Mercury (mg·kg^{-1})	0.009	0.016	0.012	0.015	<840	7.000	1	0.090
Molybednum (mg·kg^{-1})	<0.8	<1.5	<1.0	<1.4	<57	9.000	1	0.070
Nickel (mg·kg^{-1})	5.4	9.3	4.9	6.5	<75	20.600	1	0.031*
Selenium (mg·kg^{-1})	<0.8	<1.5	<1.0	<1.4	<100	9.000	1	0.070
Zinc (mg·kg^{-1})	35.2	60.9	38.5	51.5	<7,500	22.333	1	0.028*
Respirometry [carbon dioxide-carbon (mg·g^{-1} solids per day)]	0.8	—	0.6	—	<2 (very stable) 2–8 (stable)	7.000	1	0.900
Respirometry [carbon dioxide (mg·g^{-1} organic matter per day)]	2.3	—	2.1	—	<2 (very stable) 2–8 (stable)	22.000	1	0.029*
Bioassay: emergence (% of control)	100	—	100	—	>90 (very mature)	—	—	—
Bioassay: seedling vigor (%)	100	—	100	—	>95 (very mature)	—	—	—

[z]1 mmho/cm = 1 dS·m^{-1}, 1 mg·kg^{-1} = 1 ppm, 1 mg·g^{-1} = 1,000 ppm.
[y]Sargassum was manually washed with tap water and screened through a charcoal fiberglass screen wire to remove as much tar, salt, and sand as possible before composting.
[x]U.S. Composting Council (USCC) 2002.

[Garden-Ville (Creedmoor, TX), personal communication).

Compost quality tests results. The pH, soluble salt content, total nitrogen, total carbon, carbon: nitrogen ratio, particle size, bioassay, and respirometry measurements of all samples regardless of washing were within the ideal and desirable ranges for compost typically sold in the horticultural industry (Table 1). In addition, heavy-metal content did not exceed normal ranges. The compost samples were free of weed seeds, viable plant propagules of any species and pathogens (Table 1).

According to the U.S. Composting Council (2002), the ideal pH range for compost is between 5.0 and 8.5. The measurements of the samples ranged from 8.1 to 8.4. Although these measurements are alkaline, they were within the acceptable pH ranges for finished compost standards (U.S. Composting Council, 2002). Although food waste and wood chips are acidic feedstocks within compost, seaweed is slightly alkaline (Cooperband, 2002; Darlington, 2007; Dougherty, 1999; Eyras et al., 1998; Maze et al., 1993). Compost research has indicated that piles allowed to cure for 3–4 months tend to have lower pH measurements (Dougherty, 2002). Therefore, curing piles for longer than 1 month could allow the compost more time to become more acidic if deemed necessary.

Soluble salt content measured in each of the piles ranged from 1.10 to 1.59 mmho/cm and was within the safe range of 1.0–10.0 mmho/cm (U.S. Composting Council, 2002). Regardless of washing the sargassum, salt content was unaffected in the final product; therefore, prewashing seaweed did not appear to be necessary in creating a quality compost.

The normal range of total nitrogen content identified by the U.S. Composting Council (2002) is between 0.5% and 2.5% (dry weight basis). The total nitrogen content in the representative samples ranged from 0.8% to 1.0%. The ideal total carbon identified by the U.S. Composting Council (2002) is less than 54%. The range of total carbon in the samples varied from 10.8% to 13.4%. Carbon:nitrogen ratios of 20 or less allow organic nitrogen to break down to an inorganic, plant-available form of nitrogen (U.S. Composting Council, 2002). The carbon:nitrogen ratios of the samples were between 13.40 and 13.50. Therefore, the compost produced in this study should increase plant-nutrient availability when applied to soil.

Bioassay tests measured maturity of the compost based on emergence and seedling vigor. Compost was rated as "very mature" if emergence readings are greater than 90% and seedling vigor readings are greater than 95% (U.S. Composting Council, 2002). Measurements of all compost samples were identified at 100%. Respirometry tests were conducted to determine the stability (or microbial activity) in the finished compost. The U.S. Composting Council (2002) rates compost with respirometry readings of 0.1–2.0 as "very stable," whereas readings from 2.1 to 8.0 are identified as "stable." The average respirometry reading for the compost samples in this study was 2.2. Individual samples were identified within the range of 2.1–2.3. Subsequently, all compost samples were considered to be stable products for use in the industry.

Although some of the samples did not have the ideal levels of percent moisture and percent solids indicated in compost quality test standards set forth by the U.S. Composting Council (2002), overall, the compost produced was considered a quality product for the horticultural markets (Table 1). Ideally, levels of solids in compost are set at 50% to 60%, whereas the ideal moisture content is 40% to 50% (U.S. Composting Council, 2002). The washed sargassum compost samples were within the ideal ranges with moisture levels at 42.2% and solids measured 57.8%. Unwashed sargassum compost levels had a greater amount of solids (74.7%) and less moisture (25.3%). Compost created using unwashed sargassum contained greater amounts of sand from the beaches, which accounted for more solids. Higher sand content in turn decreased moisture-holding capacity within the compost. However, in some instances, higher amounts of sand in this compost may be seen as beneficial in circumstances where soils need better drainage.

Statistical comparisons. Although all compost created using sargassum met compost quality standards, independent *t* tests were used to make comparisons between washed and unwashed sargassum compost samples and some significant differences were found (Table 1). The pH of the compost piles made from washed sargassum was slightly more alkaline when compared with the piles constructed with unwashed sargassum [8.4 vs. 8.1 (Table 1)]. As mentioned previously, pH was within acceptable levels for both samples and pH will tend to become more acidic with additional curing time. There was a greater percentage OM in the unwashed vs. the washed sargassum compost piles [23% vs. 21% (Table 1)]. This was to be expected as it was noticed that some sargassum material degraded and was lost during the washing process that would lead to less organic material present. There was more potassium in the unwashed vs. the washed sargassum compost piles (0.45% vs. 0.41%), as well as magnesium (0.28% vs. 0.24%) and zinc (38 vs. 35.2 $mg \cdot kg^{-1}$) (Table 1). However, compost created with washed sargassum had higher levels of copper (10.7 vs. 10.3 $mg \cdot kg^{-1}$) and nickel (5.4 vs. 4.9 $mg \cdot kg^{-1}$) (Table 1). Again, the washed compost piles were thought to have slightly more sargassum due to losses in material in the treatment piles during washing. Algae are known to be a good source of macronutrients among other growth stimulating compounds (Verkleij, 1992). Arsenic was more prominent in the unwashed piles but still well within the standards for safety set by the Environmental Protection Agency and for compost quality (Table 1) (Woodbury, 1993).

Respirometry value comparisons showed a significant difference between the washed and unwashed compost samples [2.3 vs. 2.1 mg carbon dioxide per gram of OM per day (Table 1)]. Respirometry, a measure of compost stability, was greater for the washed sargassum compost piles when compared with the unwashed sargassum compost, but lower values demonstrate a more stable sample. However, compost quality test standards indicated the values for both samples were considered stable, cured composts with very limited potential for phytotoxicity and odor.

Trends shown here are considered preliminary given the case-study approach. Results from this study are valuable as very few studies have researched the potential of seaweeds and algae as a bioresource (Eyras et al., 1998; Gangaiah et al., 2017; Khan et al., 2009; Vendrame and Klock-Moore, 2013), and few have looked into composting these materials. This study indicated that compost created from sargassum results in a quality product. Although the feedstock was harvested from a saltwater environment, final compost products created did not include salinity levels potentially harmful to plants and can be used to promote plant health. Therefore, when the amount of sargassum that arrives on the shoreline exceeds the amount that can be integrated into dunes, the biomass can be used as a feedstock to create compost valuable to the horticultural industry. The compost may even be considered a "boutique" compost product because of the incorporation of seaweed. Seaweed has been marketed to horticulturists as a liquid fertilizer (Panda and Nayak, 2012; Verkleij, 1992).

Future studies should include a cost-benefit analysis of the removal evaluating the investment and return during harvesting and composting vs. the cost of removal and disposal into a landfill or utilization by integration into dunes which decreases beach space and potentially tourism appeal. Furthermore, as prewashing of the seaweed did not impact the final compost produced in terms of improved quality, future studies may also attempt to identify the maximum amount and proper ratios of sargassum that can be used as a feedstock for compost creation. In addition, studies comparing the nutrient levels between the two methodologies could prove to be useful for different practical applications.

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AU1) The in-text citation "Glover, 2014" was changed to "Glover et al., 2014" to match the reference list. Please check.

Willingness to Pay for a Specialty Blend Compost Product Developed from Brown Seaweed Harvested from Coastal Regions in Texas

Tina M. Waliczek[1], Nicole C. Wagner[1], and Selin Guney[2]

ADDITIONAL INDEX WORDS. **aquatic plant management, beach management, brown algae, compost quality, consumer preferences, exotic, invasive species, *Sargassum fluitans*, *Sargassum natans***

SUMMARY. **Composting is the biological decomposition of organic materials, such as plant tissue, food scraps, paper, animal fodder, and wood chips. The end-product, compost, is a beneficial soil amendment because it can contain a diversity of beneficial microorganisms, has high nutrient and water-holding capacities, can increase total soil porosity, and contains essential plant nutrients that improve soil productivity. Coastal regions of the Gulf of Mexico, as well as the Atlantic and European shorelines, have witnessed a proliferation of brown seaweed (*Sargassum* sp.). When piled on beaches, tourism appeal is reduced, threatening the local economy. When amassed offshore, thick brown seaweed mats can hinder fishing. Excessive decomposition rates can lead to eutrophication, which threatens coastal areas economically and environmentally. Despite these problems, seaweed may be considered a valuable compost ingredient. Therefore, the purpose of this study was to conduct a market test to determine the potential value of a seaweed-incorporated compost to consumers in Texas and to identify attributes of likely consumers. A marketing survey was developed and distributed to gardeners in the central and south Texas regions. Contingent valuation questions measured participants' willingness to pay for the seaweed compost products. Participants were able to see, smell, and touch a sample of the compost while completing the survey. Despite 92% of respondents ranking themselves as inexperienced in compost behavior, results indicated a potential for a specialty, competitively priced seaweed-incorporated compost to be introduced to the market. Respondents were most willing to pay \$4.00/ft³ to \$5.00/ft³ for seaweed-incorporated compost. Additionally, participants who responded positively to buying local, buying compost in the past, having positive environmental attitudes, and buying American were more likely to pay more for the seaweed-incorporated compost. There was not an obvious pattern between willingness to pay for seaweed-incorporated compost and demographic responses.**

Increasingly, composting is used as a waste management method for a variety of organic materials (Walker et al., 2006). Composting is the biological decomposition of organic and "waste" materials, such as plant tissues, food scraps, paper, animal fodder, and wood chips, into a soil-like product called "compost" (Rynk, 1992). The humus-like end product becomes a valuable soil amendment because it increases levels of organic matter (Laudicina et al., 2011), contains essential plant macro and micronutrients (Emerson, 2003; Faucette et al., 2003), stimulates microbial activity (Iovieno et al., 2009), and improves soil water-holding capacity and soil structure, which in turn reduces runoff, drought damage to plants, and the need for fertilizers (Dougherty, 1999; Foley and Cooperband, 2002; Rynk, 1992).

Coastal regions of Texas have a proliferation of brown seaweed (*Sargassum* sp.) drifting onshore especially in the spring and early summer months, which overlaps with peak tourist seasons (Sembera et al., 2018). An excess of the seaweed is harvested in all major beach areas including Galveston, Port Aransas, Corpus Christi, South Padre Island, and Mustang Island. While brown seaweed can provide food and habitat for a diversity of marine life, excessive growth of seaweed threatens coastal areas economically and environmentally. Tourists often view the seaweed mats as poor beach maintenance (Gaskill, 2015). Because these areas rely on income generated from tourists, maintaining or increasing the tourism industry is essential (Gaskill, 2015). Additionally, excessive brown seaweed is considered a nuisance because it clogs recreational boating and fishing areas, as well as traps debris. Environmentally, excessive decomposition of this organic matter can lead to eutrophication (Eyras et al., 1998) and can entrap marine life (Langin, 2018). In 2011, brown seaweed was added to the Global Invasive Species Database (Invasive Species Specialist Group, 2011).

While excessive, non-native brown seaweed biomass can have serious negative implications as described above, seaweed can be used a beneficial agricultural input. For centuries, species of seaweed have been applied directly to land to enhance plant growth and productivity, particularly in coastal areas (McHugh, 2003). Seaweeds and seaweed liquid fertilizers are commercialized and substituted for synthetic fertilizers. As reported by Begum et al. (2018), seaweed extracts are marketed as liquid fertilizer and bio-stimulants because they contain multiple growth regulators, such as cytokinins (Durande et al., 2003), auxins (Sahoo, 2000), and gibberellins (Strik and Staden, 1997). Applied to crops, seaweed extracts have

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[1]Department of Agricultural Sciences, Texas State University, 601 University Drive, San Marcos, TX 78666

[2]School of Accounting, Finance, and Economics, University of Waikato, Private Bag 3105, Hamilton 3240, New Zealand

T.M.W. is a Professor of Horticulture.

N.C.W. is an Assistant Professor.

S.G. is a Senior Lecturer.

T.M.W. is the corresponding author. E-mail: tc10@txstate.edu.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.0283	ft³	m³	35.3147
3.7854	gal	L	0.2642
0.4536	lb	kg	2.2046
1.6093	mile(s)	km	0.6214

additional benefits including the promotion of beneficial soil microorganisms (Khan et al., 2009), increased plant nutrient uptake from soil (Turan and Köse, 2004), enhanced antioxidant properties (Verkleij, 1992), increased crop tolerance to environmental stress (Zhang et al., 2003), and increased crop resistance to some pests, such as red spider mites (*Tetranychus urticae*) and aphids (Aphidoidea) (McHugh, 2003). Furthermore, seaweed and liquid seaweed manures appear to induce fruit setting and increase germination rates (McHugh, 2003; Sivasankari et al., 2006). The increased crop germination rate at low concentrations of added seaweed extract could be due to growth promoting gibberellins, as well as additional micronutrients and amino acids that positively influence crop germination (Begum et al., 2018). Given these beneficial attributes, seaweed is applied as a green manure, foliar spray, soil conditioner, and/or soil drench (Thirumaran et al., 2009).

In areas where excess brown seaweed can be an economic and environmental detriment, initiatives have been implemented to compost brown seaweed due to its value as a soil amendment and fertilizer (Eyras et al., 1998; Illera-Vives et al., 2015; López-Mosquera et al., 2011; Sembera et al., 2018). By analyzing pH, soluble salt content, macro and micronutrient content, carbon:nitrogen ratio, percent solids, and percent moisture content of composted brown seaweed, Sembera et al. (2018) found that compost created from brown seaweed resulted in a quality product for the horticultural industry. Although the quality of some brown seaweed compost can be limited due to high amount of sand and low nitrogen content, compost developed from seaweed has shown to increase soil water-holding capacity, plant growth, and plant macro and micronutrient uptake (Eyras et al., 1998; Illera-Vives et al., 2015; Michalak et al., 2017). Additionally, tomato (*Solanum lycopersicum*) grown with seaweed compost matured more quickly and showed higher resistance to disease (Eyras et al., 2008). While more research is needed to fully understand the mechanisms for these increases in yield and disease resistance, it is recognized that seaweed, which would otherwise be a waste product, can be of significant value as a composted material when used as a soil amendment (Cole et al., 2016).

The global compost market is expected to reach $9.2 billion by 2024 (PR Newswire, 2019). Within the compost industry, there has been some differentiation in products available and the prices at which they were offered based on the ingredients from which the compost was made (Walker et al., 2006). For instance, composts prepared from municipal sewage waste are generally sold at a lower price when compared with compost created with animal manures (Garden-Ville, unpublished data). Landscape blends created with topsoil, mulch, and/or sand are promoted and offered for alternative applications (Garden-Ville, unpublished data). Knowledgeable and informed consumers will often recognize that not all composts have the same attributes and that various ingredients may have differing effects, limitations, and/or benefits (Alexander, 2019). With the understanding that various compost ingredients can demand different price points and that this may be a novel product for some consumers, it is important to establish whether the potential consumers are actually interested in the product as well as identifying the potential consumers (Glover et al., 2014; van Kleef et al., 2005).

Studies have shown that consumers are influenced by their personal values. For example, one study found most consumers would buy fewer imported products if they knew the distance products had traveled (Gairdner, 2006). Hence, more interest was garnered by consumers of other types of agricultural and horticultural products regarding local sourcing (Getter and Behe, 2013; Yue et al., 2011; Zaffou and Campbell, 2016). Additionally, some consumers were affected by ethnocentricity—where they are more likely to buy products made in the United States or in their home state. For example, in Texas, the "Go Texan" campaign was developed by the Texas Department of Agriculture and is used to promote Texas products and producers (Willcox, 2015).

Thus, the purpose of this study was to conduct a market test to determine the potential value of seaweed-incorporated compost to consumers in Texas and to identify attributes of likely consumers.

Materials and methods

Brown seaweed compost. The compost used in this study was created with 48% food waste, 48% regional wood chips, and 4% dried brown seaweed by volume collected from the U.S. Gulf Coast of Texas. The compost was tested by the Agricultural Analytical Services Laboratory's U.S. Composting Council's Seal of Testing Approval Program at Pennsylvania State University (University Park) and found to be a quality product for horticultural and agricultural applications (Sembera et al., 2018).

Sample recruitment and survey administration. Individual consumers were surveyed during the spring and summer at central Texas locations where gardeners were known to gather including local garden centers, farmer's markets, the university, community centers, and churches. Targeting farmers' market patrons allowed researchers to include individuals in the study who were predisposed to participating in niche markets. This type of relationship marketing has been used to predict consumer behavior and potential markets in past studies (Shani and Chalasani, 1992; Short et al., 2017).

Consumers were presented with a 1/2-gal bucket of the specialty compost to view, feel, and smell. Participants took 15 min on average to fill out the survey, and an incentive of a packet of seeds was used to encourage participation in the study. To have consistency in presenting the survey to participants, only one researcher administered the survey.

Survey instrument. The survey included sections measuring environmental attitudes and behaviors, and behaviors related to purchasing habits such as ethnocentricity, locality, behavioral intent, and willingness to pay (WTP) for the product (Table 1). T1
Demographic information was also collected for each participant, including age, gender, and educational and income level. The survey instrument and sections were adapted from previous studies known to be reliable and valid (Cornelissen et al., 2008; Glover et al., 2014; Short et al., 2017). For each section and variable of interest

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Table 1. Descriptive statistics indicating the frequency and percentages of responses to individual statements in the study of the market potential of seaweed-incorporated compost.

Environmental statements	Strongly agree [no. (%)]	Agree	Undecided	Disagree	Strongly disagree
I feel morally obliged to protect the environment.	131 (51.0)	67 (26.1)	30 (11.7)	24 (9.3)	5 (1.9)
I think of myself as an environmentally responsible gardener.	118 (46.3)	58 (22.7)	35 (13.7)	32 (12.5)	12 (4.7)
I believe that I behave in an environmentally conscious way.	102 (40.0)	94 (36.9)	28 (11.0)	26 (10.2)	5 (2.0)
Organic agriculture is good for the environment.	184 (71.6)	58 (22.6)	13 (5.1)	2 (0.8)	0 (0)
It is important that each individual be aware of environmental concerns.	138 (53.7)	95 (37.0)	19 (7.4)	5 (1.9)	0 (0)
My friends think that I should use eco-friendly products in my garden.	90 (36.0)	71 (28.4)	63 (25.2)	20 (8.0)	6 (2.4)
All plants and animals play an important role in the environment.	150 (58.6)	94 (36.7)	8 (3.1)	4 (1.6)	0 (0)
Industries should be held financially responsible for any pollution they cause.	141 (54.9)	59 (23.0)	32 (12.5)	11 (4.3)	14 (5.4)
Government should make laws to make recycling mandatory.	112 (43.9)	65 (25.5)	31 (12.2)	27 (10.6)	20 (7.8)

Ethnocentricity statements	Strongly agree [no. (%)]	Agree	Undecided	Disagree	Strongly disagree
It is not right to purchase foreign products, because it puts Americans out of jobs.	46 (18.0)	72 (28.2)	62 (24.3)	52 (20.4)	23 (9.0)
Only those products that are not available in the U.S. should be imported.	42 (16.4)	84 (32.8)	80 (31.3)	32 (12.5)	18 (7.0)
It is always best to purchase American products.	56 (22.0)	90 (35.4)	60 (23.6)	31 (12.2)	17 (6.7)
American products first, last, and foremost.	50 (19.7)	64 (25.2)	71 (28.0)	51 (20.1)	18 (7.1)
American people should always buy American products instead of imports.	46 (18.0)	76 (29.8)	69 (27.1)	47 (18.4)	17 (6.7)

Locality: How often have you bought food in the following categories?	Very often [no. (%)]	Often	Occasionally	Rarely	Not at all
Local fresh fruits and vegetables	79 (31.9)	74 (29.8)	63 (25.4)	20 (8.1)	10 (4.0)
Local dairy products	51 (19.8)	54 (21.8)	75 (30.2)	44 (17.7)	23 (9.3)
Local meats	49 (19.8)	63 (25.4)	72 (29.0)	44 (17.7)	20 (8.1)
Local processed foods (e.g., breads, jam)	39 (15.7)	53 (21.4)	98 (39.5)	36 (14.5)	22 (8.9)
Local eggs	63 (25.5)	50 (19.5)	75 (30.4)	37 (15.0)	22 (8.9)

	Strongly agree [no. (%)]	Agree	Undecided	Disagree	Strongly disagree
I prefer to buy locally.	121 (53.7)	95 (37.0)	19 (7.4)	5 (1.9)	0 (0)

	25 miles[z] [no. (%)]	50 miles	150 miles	400 miles
What is the longest distance from your garden that you would consider to be a "local" product?	74 (29.8)	88 (35.5)	71 (28.6)	15 (6.0)

Compost behavior	Yes [no. (%)]	No	I don't know	Does not apply to me
I bought compost in the last year.	119 (49.2)	105 (43.4)	7 (2.9)	2 (0.8)

(*Continued on next page*)

Table 1. (*Continued*) Descriptive statistics indicating the frequency and percentages of responses to individual statements in the study of the market potential of seaweed-incorporated compost.

	Response options				
	Strongly agree	**Agree**	**Undecided**	**Disagree**	**Strongly disagree**
Environmental statements	**[no. (%)]**				
I typically buy compost at a box store (e.g., Wal-Mart (Bentonville, AR), Lowe's (Mooresville, NC), Home Depot (Atlanta, GA).	131 (61.8)	68 (32.1)	13 (6.2)	0 (0)	
I typically buy compost at a local garden center.	102 (48.6)	96 (45.7)	1 (0.5)	11 (5.3)	
My family and I used kitchen scraps, leaf litter, and other organic materials to make compost.	90 (39.0)	131 (56.7)	3 (1.3)	7 (3.0)	
I used chemical-based fertilizers on my garden this year.	163 (75.1)	43 (19.8)	11 (5.1)	0 (0)	
I used a chemical-based weed-killer in my yard within the last year.	152 (67.9)	63 (28.1)	9 (4.0)	0 (0)	
I used a chemical-based fungicide in my yard in the last year.	172 (76.8)	38 (17.0)	14 (6.2)	0 (0)	
I intend to use eco-friendly compost in the garden in the next year.	60 (26.4)	146 (64.3)	19 (8.3)	2 (0.9)	
When I've used compost in the past, my plants seem healthier.	41 (19.0)	139 (64.4)	31 (14.4)	5 (2.4)	
	\$3 or less	**\$4**	**\$5**	**\$6**	**\$7 or more**
Willingness to pay	**[no. (%)]**				
What would be a base price you'd be willing to pay for a 1 ft^3 bag, based on the sample you see before you?	18 (7.7)	88 (37.4)	63 (26.8)	50 (21.3)	16 (6.8)
How much more would you be willing to pay for each of the following characteristics?	**+\$1**	**+\$2**	**+\$3**	**+\$4**	**+\$5 or more**
	[no. (%)]				
Locally or Texas-produced	63 (26.8)	73 (31.1)	46 (19.6)	26 (11.1)	27 (11.5)
Protects against drought stress/insulates roots	40 (17.2)	98 (42.2)	47 (20.2)	34 (14.7)	13 (5.6)
Diverts organic materials from landfills	55 (23.4)	78 (33.2)	49 (20.9)	30 (12.8)	23 (9.9)
Is a naturally based product	64 (27.9)	73 (31.9)	39 (17.0)	29 (12.7)	23 (10.0)

[z]1 mile = 1.6093 km.

within the instrument, respondents were scored and classified into categories established a priori as positive, indifferent, or low. Similar groupings were established and used in interpreting results in previous studies (McFarland et al., 2008, 2010).

Potential compost users' environmental attitude scores. Respondents were asked nine questions related to their environmental attitude. These questions were rated on a 5-point Likert scale. Examples of questions included, "it is important that each individual be aware of environmental concerns," "industry should be held financially responsible for any pollution they cause," "government should make laws to make recycling mandatory," and "all plants and animals play an important role in the environment" (Table 1). Possible answers to the statements included "strongly agree," "agree," "undecided," "disagree," and "strongly disagree." Responses of "strongly agree" received 5 points, while responses of "agree" received 4 points, responses of "undecided" received 3 points, responses of "disagree" received 2 points, and responses of "strongly disagree" received 1 point. Possible scores ranged from 5 to 45 points, and respondents were classified as having negative (5–15 points), indifferent (16–30 points), and positive (31–45 points) environmental attitudes based on their environmental attitude scores. The Cronbach's alpha reliability score for these questions was 0.905.

Potential compost users' views on ethnocentricity. Five ethnocentricity questions focused on whether American-made products are more desirable to participants and were rated on 5-point Likert scale. Examples of questions included "it is not right to purchase foreign products, because it puts Americans out of jobs" and "only those products that are not available in the U.S. should be imported." Possible answers were "strongly agree," "agree," "undecided," "disagree," and "strongly disagree", and points were attributed to responses as indicated above (Table 1). Possible scores ranged from 5 to 25 points and respondents were classified as having low (5–8 points), indifferent (9–16 points), and positive (17–25 points) ethnocentricity based on their ethnocentricity scores. These questions generated Cronbach's alpha of 0.925.

Potential compost users' locality scores. The locality questions of the survey focused on respondents' local food-use. Respondents were presented with five statements relating to their locality, which were rated on 5-point Likert scale. Examples of questions included asking the respondent how often he/she had purchased various types of local food from categories, including local fresh fruits and vegetables, eggs, and dairy products (Table 1). Possible answers were "very often," "often," "occasionally," "rarely," and "not at all." Responses of "very often" received 5 points, while responses of "often" received 4 points, responses of "occasionally" received 3 points, responses of "rarely" received 2 points, and responses of "not at all" received 1 point. Possible scores ranged from 5 to 25 points, and respondents were classified as having negative (5–8 points), indifferent (9–16 points), and positive (17–25 points) attitudes toward locality based on their locality scores. Additional questions asked the farthest distance respondents considered to be local to them, as well as their overall preference for purchasing locally. A reliability analysis indicated a Cronbach's alpha of 0.741 for these questions (Table 1).

Potential compost users' compost behavior scores. The compost behavior questions of the survey focused on respondents' compost-use in the garden. Respondents were presented nine statements relating to their compost behavior, and these statements were rated on a 4-point scale that included the binary options of "yes" and "no," as well as the options of "I don't know" and "does not apply to me." Examples of questions included, "I intend to use eco-friendly compost in my garden in the next year" and, "when I've used compost in the past, I noticed that my plants seemed healthier." Responses of "yes" received 4 points, while responses of "no" received 3 points, responses of "I don't know" received 2 points, and responses of "does not apply to me" received 1 point (Table 1). Respondents were classified as being inexperienced (0–12 points), moderately experienced (13–24 points), or highly experienced (25–36 points) with compost based on their compost behavior scores. Possible scores ranged from 9 to 36 points. These questions generated Cronbach's alpha of 0.796.

Potential compost users' self-reported willingness to pay. The WTP questions of the survey were used to determine respondents' willingness to pay for this specialty blend compost. Questions and methods were shown to be valid and reliable in recent past studies (Glover et al., 2014; Short et al., 2017). Respondents were presented six statements rated on two different 6-point pricing scales for price of a 1-ft^3 bag: 1) \$0, \$3 or less, \$4, \$5, \$6, and \$7 or more, and 2) none, \$1, \$2, \$3, \$4, and \$5 or more. Examples of questions included, "what would be a base price you'd be willing to pay for a 1-ft^3 bag, based on the sample you see before you?" and, "assuming bags of compost are priced at \$3.00/ft^3 at your local nursery/garden center, how much more would you be willing to pay for each of the following characteristics?" (Table 1). Answers indicating greater values received 5 points and possible scores ranged from 0 to 30 points. Respondents were classified as having low (0–10 points), indifferent (11–20 points), or positive (21–30 points) WTP based on their WTP scores (Table 1). A reliability analysis indicated a Cronbach's alpha of 0.931.

Data analysis for potential compost users' survey responses. Descriptive statistics and frequencies were used to analyze the data from the potential compost users. Individuals' WTP, environmental attitudes, locality, ethnocentricity, and compost behavior scores were compared with their age, education, household income, and gender. Using a SPSS statistical package (version 20; IBM, Armonk, NY), Pearson's product-moment tests were applied to assess the relationships between the above variables, and analysis of variance (ANOVA) tests were adopted to look for differences between the variables of interest. A lack of response to individual questions within the survey were treated as missing data within those cells.

Results

Potential compost users' survey. Surveys were collected from 257 potential compost users. Demographics of this study are reflective of previous studies of similarly minded consumers of interest in farmers' market studies (Glover et al., 2014) and gardening studies (Boyer et al., 2002). In analyzing the demographics of the sample, the age of respondents was more heavily weighted toward younger groups with 40.6% of people surveyed being between 25–44 years, and 32.9% being under 25 years old. The percentage of respondents who were between 45 and 59 years old was 21.3%; only 5.2% of respondents were over 60 years old (Table 2). Of all the participants in the sample, 55.1% were female and 44.9% were male (Table 2).

The sample was well educated and within the moderate to moderately high-income bracket. About, 47% of the sample stated that they had achieved either bachelor's degree (29.2%) or graduate degree (20.6%), and 40.3% mentioned having either associate degree or some college with no degree (14.8% and 25.5%, respectively). Only 9.4% of the sample indicated they had a high school diploma or a lower level education (Table 2). About 34% of the sample was in the moderate to moderately high-income bracket of \$35,000 and \$74,999 (Table 2).

Potential compost users' environmental attitude scores. The majority (78%) of respondents had a positive environmental attitude, whereas 23% of respondents had an indifferent environmental attitude. No respondents had a low environmental attitude. For example, a little over 75% of respondents felt a moral obligation to protect the environment and behave in an environmentally conscious way (Table 1). Nearly 95% of respondents agreed or strongly agreed that organic agriculture practices are good for the environment, while over 68% felt they were environmentally responsible gardeners (Table 1). Consistent with findings that the garden retail industry is influenced by sociocultural drivers that include consumer positive environmental attitudes and behavior (Horticultural Trades Association, 2017), these findings suggested that gardeners and those frequenting garden centers are inclined to have a positive environmental attitude.

Potential compost users' views on ethnocentricity. Results showed that 47% of respondents ranked as having a positive ethnocentric attitude, whereas 46% of respondents ranked as having an indifferent ethnocentric attitude, and 7% of respondents ranked as having a low ethnocentric attitude. For example, on all category statements, 25% to 30% of respondents were undecided regarding statements relating to products being American made (Table 1). While some studies show ethnocentric attitudes may impact purchasing decisions (Shimp and Sharma, 1987), others have found these beliefs may or may not hold true

Table 2. Analysis of variance comparisons of willingness to pay (WTP) and the demographic variables of age, education, income, and gender in the study of the market potential of seaweed-incorporated compost.

Group	[no. (%)]	WTP mean score (0–30 scale)[z]	SD	df	*F*	*P*
Age group (years)				4	0.26	0.903
Under 25	82 (32.9)	16.207	7.929			
25–44	101 (40.6)	15.514	7.285			
45–59	53 (21.3)	15.886	7.397			
60–84	12 (4.8)	16.416	8.649			
85+	1 (0.4)	10.000	NA			
Gender				1	1.46	0.228
Female	134 (55.1)	16.350	7.656			
Male	109 (44.9)	15.174	7.416			
Income				6	1.85	0.090
Less than $14,999	55 (23.1)	16.345	7.359			
$15,000–$24,999	14 (5.9)	13.428	6.676			
$25,000–$34,999	42 (17.6)	13.381	6.431			
$35,000–$74,999	87 (36.6)	16.459	7.839			
$75,000–$99,999	22 (8.6)	17.318	6.917			
$100,000–$149,999	11 (4.6)	19.818	9.505			
$150,000 and over	7 (2.9)	14.857	7.335			
Education				6	2.69	0.015*
Less than ninth grade	3 (1.2)	11.333	8.326			
Ninth–12th grade, no diploma	3 (1.2)	23.333	1.527			
High school graduate or equivalent	18 (7.0)	13.166	7.398			
Some college, no degree	62 (25.5)	15.967	8.681			
Associate's degree	36 (14.8)	12.750	4.789			
Bachelor's degree	71 (29.2)	17.352	6.989			
Graduate or professional school/degree	50 (20.6)	16.460	7.877			

[z]Higher WTP values indicated a greater price in WTP for the seaweed-incorporated compost whereas lower WTP indicated a lesser price in WTP for the seaweed-incorporated compost.
*Statistically significant at the 0.05 level.

in actual purchasing decisions (McLain and Sternquist, 1992).

Potential compost users' locality scores. Fifty percent of respondents ranked as having a positive locality attitude, whereas 43% of respondents ranked as having an indifferent locality attitude, and 7% of respondents ranked as having a negative locality attitude. Past research found farmers' market patrons to have a medium level of concern toward locally sourced foods (Glover et al., 2014). In this study, close to 90% of respondents said they prefer to buy locally, and most respondents felt that a product would be locally sourced if it was produced within 150 miles (Table 1).

Potential compost users' compost behavior scores. Almost 92% of respondents ranked in the inexperienced in compost behavior category, whereas 8% of respondents ranked in the moderately experienced in compost behavior category, and less than 1% of respondents ranked in the highly experienced in compost behavior category. Therefore, in this study, most respondents considered themselves a novice regarding their purchase and use of compost. Most respondents in this study were using chemical-based fertilizers, weed-killers, and fungicides in their gardens (Table 1). Many reported purchasing compost at both big-box stores and local garden centers (Table 1). Most respondents also reported composting their own home organic waste (Table 1). Less than 20% reported having healthier plants after using compost in the past, and a little over 26% responded that they intended to purchase compost next year (Table 1). Walker et al. (2006) found in their survey study that 31% of respondents reported valuing compost as an alternative for chemical additives, with 64% reporting positive experiences with compost.

Potential compost users' self-reported willingness to pay. About, 15% of respondents ranked as having a positive WTP attitude, while 53% of respondents scored as having an indifferent WTP attitude, and 32% of respondents had a low willingness to pay attitude. Respondents were most willing to pay $\$4.00/ft^3$ to $\$5.00/ft^3$ for seaweed-incorporated compost (Table 1). Most respondents reported they would pay $1.00 to $5.00 or more given additional information regarding the impact of the product on protecting from drought stress, the product being locally or Texas-produced, the product helping to divert organic materials from landfills, and the product being a naturally based (Table 1).

These results indicate a wide breadth of compost users' WTP among the study sample size. Compost prices range from $1.36 (Lowes Companies, Mooresville, NC) to $13.42 (Wal-Mart Stores, Bentonville, AR) per 40- to 50-lb or 1- to 2-ft^3 bag. It should be noted as a limitation of the study that this research only looked at stated prices consumers claimed they would pay for the compost. Findings on the actual amount consumers would pay could vary had they been forced to purchase the compost.

Demographic comparisons of willingness to pay among potential compost users. According to ANOVA results that compared the mean scores of each demographic category and their WTP, statistical significance (P = 0.015) was only found for education and WTP. Post-hoc analysis (LSD) indicated "less than 9th grade," "9th to 12th grade, no diploma," "Associate degree," "high school graduate or equivalent," "Bachelor's degree," "some college, no degree," "graduate or professional degree," were significantly different from each other. However, based on the results of post-hoc analysis, there was not an obvious correlation between WTP and education levels of the participants. For all the other demographic variables, all groups within comparisons of age, gender, and income were similar in the potential price they were willing to pay for the specialty compost (Table 1). These findings were consistent with other horticultural product purchasing studies. For example, Short et al. (2017) found no difference in WTP regarding locally grown specialty cut sunflowers based on age, income, and education.

Locality score comparisons. A Pearson's product-moment correlation indicated a positive correlation (r = 0.326, P < 0.001) between WTP and locality scores. Therefore, as the locality scores increased, the potential users' willingness to pay increased as well (Table 3). Past research found consumers were willing to pay more for products indicating they were locally produced on the label (Hu et al., 2012).

Compost behavior comparisons. A Pearson's product-moment correlation indicated a positive correlation (r = 0.156, P = 0.013) between WTP and compost behavior scores. Therefore, as the compost behavior scores increased, such that users with more compost use experience had higher behavior scores, the potential users' WTP increased as well (Table 3). This supports previous work showing that increased awareness of organic soil and compost products promotes market development (Eggerth et al., 2007; Tyler, 2001). Education and advertising regarding compost and its benefits is something the industry should pursue. Other agricultural advertising campaigns, such as "Go Texan" were successful in enlightening consumers in the past (Willcox, 2015).

Environmental attitude comparisons. The results of the Pearson's product-moment correlation also indicated a positive correlation (r = 0.340, P < 0.001) between WTP and environmental attitude scores. As environmental attitude scores increased, the potential users' WTP increased as well (Table 3). This finding supported past research indicating that environmental attitudes can influence consumer behaviors with those concerned with the environment buying more "green" products (Mainieri et al., 1997). Glover et al. (2014) also found a positive correlation between environmental attitudes and WTP (specifically for a native plant product as a local food source), and that respondents' attitudes to the environment were related to WTP.

Ethnocentricity comparisons. A Pearson's product-moment correlation indicated a positive correlation (r = 0.169, P = 0.006) between WTP and ethnocentricity scores. So, as ethnocentricity scores increased, the potential users' WTP increased as well (Table 3).

Overall, results showed that participants who responded positively to buying local, buying compost in the past, having positive environmental attitudes, and buying American-made products were more likely to pay more for the seaweed-incorporated compost. Also, positive correlations were found regarding WTP and the following individual statements used to advertise the product (Assuming bags of compost are priced at \$3.00/ft^3 at your local nursery/garden center, how much more would you be willing to pay for each of the following characteristics?). For example, respondents were willing to pay more for "locally or Texas-produced compost" (Pearson's correlation = 0.952, P < 0.001) or for a "natural-based product" (Pearson's correlation = 0.882, P < 0.001). Those responding were also willing to spend more knowing they were "diverting materials from landfills" (Pearson's correlation = 0.951, P < 0.001) or that the product would offer "protection against drought stress" (Pearson's correlation = 0.931, P < 0.001). Thus, as indicated earlier with descriptive statistics, respondents said they would pay additionally if the seaweed-incorporated compost was advertised using these phrases (Table 3).

Conclusions

Because there have been a limited number of marketing studies that investigated the use of brown seaweed in compost and consumer WTP for seaweed-incorporated compost, this study provides a starting point for understanding the market opportunities for composting brown seaweed. Since the residential sector represents a sizeable market for soil amendments (Eggerth et al., 2007), results indicated there is potential for a specialty seaweed-incorporated compost to be introduced to the retail market, if the price is competitive. Overall, respondents were most willing to pay for seaweed-incorporated compost that was \$4.00/ft^3 to \$5.00/ft^3.

Interestingly, there was participant support for seaweed-incorporated compost despite a large majority of participants who ranked themselves as inexperienced in the compost behavior

Table 3. Correlation matrix indicating the Pearson's product-moment correlation between willingness to pay (WTP) rating and environmental attitudes, locality, ethnocentricity, and compost behavior in the study of the market potential of seaweed-incorporated compost.

Group	Pearson's correlation	P
Locality scores[z]	0.326	0.000*
Compost behavior scores[y]	0.156	0.013*
Environmental attitude scores[x]	0.340	0.000*
Ethnocentricity scores[w]	0.169	0.006*

[z]Locality scores ranged from 5 to 25 points. Higher locality scores indicated a greater amount of locally produced products purchased by the participant, and a lower locality score indicated less locally produced products purchased by the participant.
[y]Compost behavior scores ranged from 0 to 36 points. Higher scores indicated more consumer experience in purchasing compost and compost products.
[x]Environmental attitude scores ranged from 5 to 45 points. Greater environmental attitude scores indicated a greater sensitivity to issues concerning the environment, and a lower environmental attitude scores indicated a lower sensitivity to issues concerning the environment.
[w]Ethnocentricity scores ranged from 5 points to 25 points. Higher scores indicated a greater desire to purchase and promote American-made products.
*Statistically significant at the 0.05 level.

category. And, as compost behavior (i.e., more compost purchasing experience) scores increased, the potential users' WTP increased as well. Therefore, it is reasonable to assume that inexperienced users are likely not fully aware of the potential benefits of seaweed-incorporated compost. As noted by Eggerth et al. (2007), several marketing studies of organic soil amendments produced from various municipal waste sources have illustrated that market development is an issue of instilling awareness in potential users (Alexander, 2019). Eggerth et al. (2007) recommends that imparting awareness in the public is the first step where the compost market is small, which may be accomplished through education and salesmanship (Tyler, 2001). Because seaweed-incorporated compost is currently a small market within a growing compost market (Alexander, 2019), and study participants' lack of compost experience may be indicative of experience levels in general, a comprehensive education program is an area that needs further investigation in the future market development of this product. As reported by Alexander (2019), markets grow faster especially when compost education provided as needed, and when several compost producers are competing within one geographic area.

When considering consumer attitudes, behavior, and future market development, it is clear participants who responded positively to the activities of buying local, buying compost in the past, having positive environmental attitudes, and buying American were more likely to pay more for the seaweed-incorporated compost. Because more informed gardeners recognize that not all composts have the same attributes, it is important to have an understanding of the competition to new products [such as a specialty compost product and in this case, a seaweed-incorporated compost (Alexander, 2019)]. Additionally, the lack of association of demographics to WTP is helpful when identifying potential compost consumers.

Overall, this project provided a path toward creating long-term sustainable use of resources and educating the public on the value of brown seaweed, both as habitat along the Gulf of Mexico shoreline and a horticultural asset. Results could be used to improve best management practices for ecologically and economically sustainable beach maintenance in coastal regions; however, future research is suggested. Specifically, composting studies should investigate the optimum inclusion rate of seaweed, as well as the approximate available amount of seaweed that could readily be composted in municipalities. Additionally, WTP studies could incorporate a comparison compost containing no specialty ingredients in future studies when surveying participants.

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