COMPOSTING AS AN ALTERNATIVE MANAGEMENT SYSTEM FOR WILD TARO *(COLOCASIA ESCULENTA)* AND BROWN ALGAE *(SARGASSUM FLUITANS* AND *SARGASSUM NATANS)*

by

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INTRODUCTION

Background

Invasive species pose a threat to plant and wildlife communities worldwide. The threats of invasive species are now considered to be a major detrimental factor of global change (Sakai et al. 2001, Vitousek et al. 2001). Exotic and invasive aquatic species negatively impact local biodiversity, nutrient and light competition, oxygen availability, existence of native shoreline vegetation and human recreation and activity (Atkins and Williamson 2008, Reichard and White 2001, Vitousek et al. 1996). Traits that promote invasiveness include the ability to reproduce asexually, competitive ability, rapid maturity rates and adaption to environmental stresses (Sakai et al. 2001). Aquatic invasives have the additional advantage of being connected to waterways allowing rapid spread after flooding events and/or human activity. Public and private spending to prevent, control or eliminate exotic invasive species has been estimated to exceed $100 million dollars each year (Masser 2007, Simberloff 2003).

Wild taro [*Colocasia esculenta* (L.) Schott] is an exotic species invasive to the San Marcos River ecosystem (Akridge and Fonteyn 1981, Atkins and Williamson 2008, Gonzalez and Christofferson 2006, Nelson and Getsinger 2000, Nesom 2009). It thrives in freshwater swamps, streambanks, soils with high acidity and/or riparian areas with rocky crevices that provide strong footholds (MacDonald et al. 2008, Matthews 2003). Wild taro is identified as an invasive species in freshwater regions throughout the southeastern United States as well as Puerto Rico, Jamaica and India (Atkins and Williamson 2008, Bindu and Ramasamy 2008, Everitt et al. 2007, Gonzalez and Christofferson 2006, Kurien and Ramasamy 2005, MacDonald et al. 2008, Texas Invasive Plant and Pests Council [TIPPC] 2008).

Sargassum fluitans was added to the Global Invasive Species Database in 2011 (Invasive Species Specialist Group [ISSG] 2011). Massive drifts of brown algae, known collectively and colloquially as Sargassum (*Sargassum fluitans* and *Sargassum natans*[1]), float onto the United States Gulf and Atlantic coasts and European shorelines with regularity throughout the spring and summer months. Mats of Sargassum can reach heights on the shoreline of 1.2 m (4 ft) and stretch to the size of multiple football fields (Williams and Feagin 2007). In order to maintain tourist appeal and, subsequently, the tourist industry, the standard practice of Texas beach communities has been to remove the seaweed mechanically. The biomass is then piled along dunes near the shoreline (D. Herzog, personal communication, June 13, 2012).

Composting is the natural process of breaking down organic matter into a usable, waste-free product. Composting is increasingly used as a waste management method and can also provide a valuable commodity to agricultural, horticultural and related users (Rynk 1992, Walker et al. 2006). Composting that reaches high temperatures of approximately 54 C to 66 C has the potential to kill seeds and additional propagules of various plant species (Dougherty 1999, Meier 2011, Wiese et al. 1998). Using composting to manage invasive or problematic species has shown to be effective for the management of aquatic invasives including Georgia cane (*Arundo donax*), hydrilla (*Hydrilla verticillata*), water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) while creating a valuable agricultural and horticultural commodity (Meier 2011, Montoya et al. 2013).

Problem Statement

This project examined large-scale compost management of 3 aquatic species: *Colocasia esculenta* (wild taro), *Sargassum fluitans* and *Sargassum natans* (brown

[1] *Sargassum fluitans* and *Sargassum natans* will be referred to collectively as Sargassum in this project.

algae, collectively). Each species posed threats to local ecosystems in Texas. This study investigated whether compost management systems offer an effective alternative means of management by rendering the seeds and additional propagules of these species unviable, while creating a marketable byproduct for use in agriculture, horticulture and related markets.

Purpose

The purpose of this project was to evaluate the potential to manage the invasive species wild taro (*Colocasia esculenta*) and brown algae (*Sargassum fluitans* and *Sargassum natans*) in Texas using a large-scale composting system.

Objectives

The objectives of this study included (1) identifying invasive or problematic species with widespread distribution in Texas that posed a threat to local ecosystems, (2) understanding how each species grew, propagated and functioned in local plant and wildlife communities, (3) evaluating if the natural compost process effectively killed seeds and other propagules as well as eliminated potentially high levels of salinity and (4) determining if large-scale compost management of these organisms offered an effective alternative to current management systems while creating safe, marketable products for the agricultural and horticultural consumer.

Hypotheses

The hypotheses of this study were (1) heat created by large-scale compost piles would render wild taro (*Colocasia esculenta*) and brown algae (*Sargassum fluitans* and *Sargassum natans*) seeds and additional plant propagules inviable, (2) wild taro (*Colocasia esculenta*) and brown algae (*Sargassum fluitans* and *Sargassum natans*) would be a valuable feedstock for use in large-scale composting operations, (3) compost produced using wild taro (*Colocasia esculenta*) and brown algae

(*Sargassum fluitans* and *Sargassum natans*) at appropriate feedstock amounts would be valuable and of acceptable quality determined by the Compost Tests for the United States Composting Council's Seal of Testing Approval Program (STA Program) as analyzed by the Pennsylvania State University Agricultural Analytical Services Laboratory and (4) large-scale compost management would be a safe, effective and valuable way to dispose of the invasive species wild taro (*Colocasia esculenta*) and brown algae (*Sargassum fluitans* and *Sargassum natans*).

Definition of Terms

Adventitious - "growing from an unusual position, e.g. roots from a leaf or stem" (Allaby 1992, p. 8).

Aerobic respiration - "a type of respiration in which foodstuffs (usually carbohydrates) are completely oxidized to carbon dioxide and water, with the release of chemical energy, in a process requiring atmospheric oxygen" (Martin and Hine 1999, p. 11).

Algae - "a group of unrelated simple organisms that contain chlorophyll and live in aquatic habitats and moist situations on land" (Martin and Hine 1999, p. 17).

Alien species (aka exotic / nonindigenous / nonnative species) - "any species, including its seeds, eggs, spores, or other biological material capable of propagating, that species, that is not native to the particular ecosystem in which it is found... Not all alien species are invasive" (National Oceanic Atmospheric Administration [NOAA] 1997, p. 1).

Apex - "tip or extremity of an organ" (Cook et al. 1974, p. 551).

Asexual reproduction - "reproduction in which new individuals are produced from a single parent without the formation of gametes. It occurs chiefly in lower animals, microorganisms and plants. The chief methods are... fission, fragmentation, budding, vegetative propagation and spore formation" (Martin and Hine 1999, p. 47).

Axil - "the upper angle formed between the axis and any organ that arises from it" (Cook et al. 1974, p. 551).

Axis - "the main or central line of development of any plant or organ; the main stem" (Cook et al. 1974, p. 551).

Bacteria - "a diverse group of ubiquitous microorganisms all of which consist of only a single cell that lacks a distinct nuclear membrane and has a cell wall of a unique composition" (Martin and Hine 1999, p. 57).

Basal stem - "the base of a bulb" (Mathew and Swindells 1994, p. 9).

Berry - "a simple fruit having a pulpy or fleshy ovary wall" (Cook et al. 1974, p. 551).

Blade - "the usually flattened structure of a leaf, extending from the stem above the sheath" (Loflin and Loflin 2006, p. 181).

Biomass - "the total mass of all the organisms of a given type and/or in a given area" (Martin and Hine 1999, p. 73).

Bract - "a modified leaf with a flower or inflorescence in its axil. Bracts are often brightly colored and may be mistaken for the petals of a flower" (Martin and Hine 1999, p. 82).

Bud - "an outgrowth from a parent organism that breaks away and develops into a new individual in the process of budding" (Martin and Hine 1999, p. 87).

Budding - "a method of sexual reproduction in which a new individual is derived from an outgrowth (bud) that becomes detached from the body of a parent" (Martin and Hine 1999, p. 87).

Bulb - "(plants that) consist of a short basal stem covered with several protective fleshy leaf scales wrapped around a growing point... In most cases, the bulb is enclosed with a tunic of stales, and this forms a tough, protective coat" (Mathew and Swindells 1994, p. 9).

Commodity - "a raw material or agricultural product that can be bought and sold; something useful or valuable" (Soanes 2002, p. 164).

Compost - "a mixture of decaying organic matter, such as vegetation and manure, that is used as fertilizer. The organic material is decomposed by aerobic, saprotrophic organisms, mostly fungi and bacteria" (Martin and Hine 1999, p. 139).

Composting - "managed biological oxidation process that converts heterogeneous organic matter into a more homogenous, fine-particled, humus-like material" (Dougherty 1999, p. 1).

Corm - "an underground storage organ formed from a swollen stem base often bearing adventitious roots and scale leaves. Often it is renewed annually, each new rhizome forming on top of the preceding one" (Allaby 1992, p. 105).

Cultivar - "a plant variety that has been produced in cultivation by selective breeding" (Cultivar, n.d.).

Curing - "the last stage of the composting process that occurs after most of the organic feedstock material has been decomposed and stabilized" (Dougherty 1999, p. 15).

Ecosystem - "a biological community of interacting organisms and their environment" (Soanes 2002, p. 259).

Eutrophication - "describing a body of water with an abundant supply of nutrients and a high rate of formation of organic matter by photosynthesis... (due to supply of sewage or fertilizers). This stimulates excessive growth of algae" (Martin and Hine 1999 p. 218).

Evapotranspiration - "the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants" (Evapotranspiration, n.d.).

Feedstock - "raw material to supply or fuel a machine or industrial process" (Feedstock, n.d.).

Foredune - "a dune occuring at the landward margin of the beach and generally forming part of a fore-island dune ridge" (Weise and White 1980, p. 86).

Fore-island dune ridge - "a ridge of dunes parallel to the shoreline of an ocean or gulf, occuring immediately landward of the beach and at least partially stabilized by vegetation" (Weise and White 1980, p. 86).

Fragmentation - "a method of asexual reproduction in which parts of the organism break off and subsequently differentiate and develop into new organisms" (Martin and Hine 1999, p. 243).

Fruit - "a mature ovary or ovaries with or without closely related parts" (Cook et al. 1974).

Fungus (pl: fungi) - "a spore-producing organism, such as a mushroom, that has no leaves or flowers and grows on other plants or on decaying matter" (Soanes 2002, p. 333).

Germinate - "(of a seed or spore) begin to grow and put out shoots after a period of being dormant" (Soanes 2002, p. 345).

Glyphosate - "a herbicide, marketed as Roundup or Tumbleweed, that kills a variety of plants but shows little persistence in soil and low toxicity to animals" (Martin and Hine 1999, p. 270).

Growth - "a normal process of increase in size of an organism as a result of accretion of tissue similar to that originally present" (Growth, n.d.).

Headwaters - "streams forming the source of a river" (Soanes 2002, p. 383).

Herbaceous - "describing a plant that contains little permanent woody tissue" (Martin and Hine 1999, p. 286).

Humus - "the dark-coloured material that constitutes the organic components of soil" (Martin and Hine 1999, p. 299).

Inflorescence - "a particular arrangement of flowers on a single main stalk of a plant" (Martin and Hine 1999, p. 315).

Invasive species (or nuisance species) - "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health" (NOAA 1997, p. 1).

Karst - "landscape underlain by limestone which has been eroded... producing ridges, towers, fissures, sinkholes and other characteristic landforms" (Karst, n.d.).

Leach - "(with reference to a soluble chemical or mineral) drain away from soil, ash, or similar material by the action of percolating liquid, especially rainwater" (Leach, n.d.).

Microorganism - "a microscopic organism, especially a bacterium, virus, or fungus“ (Microorganism, n.d.).

Monotypic - "composed of or having only 1 type or kind" (Monotypic, n.d.).

Morphology - "the study of the form and structure of organisms, especially their external form" (Martin and Hine 1999, p. 390).

Native species - "indigenous to a region" (Loflin and Loflin 2006, p. 184).

Organic - "1). relating to or derived from living matter; 2). (of food or farming methods) produced or involving production without the use of chemical fertilizers, pesticides, or other artificial chemicals" (Organic, n.d.).

Oxalic acid - "a crystalline solid $(COOH)_2$ that is slightly soluble in water, strongly acidic and very poisonous" (Martin and Hine 1999, p. 429).

Oxidation - "a chemical reaction with oxygen... a reaction that (involves) loss of electrons and increase in oxidation number" (Martin and Hine 1999, p. 429).

Pelagic - "describing organisms that swim or drift in a sea or lake, as distinct from those that live on the bottom" (Martin and Hine 1999, p. 443).

Peltate - "off a leaf: having the petiole joined to the blade at or near the middle rather than at the margin" (Peltate, n.d.).

Perennial - "a plant that lives for a number of years" (Martin and Hine 1999, p. 446).

Petiole - "the stalk that attaches a leaf blade to the stem" (Martin and Hine 1999, p. 450).

Photosynthesis - "the process by which green plants use sunlight to form nutrients from carbon dioxide and water" (Soanes 2002, p. 630).

Phytotoxin - "a poisonous substance derived from a plant" (Phytotoxin, n.d.).

Planktonic - "(of) the small and microscopic organisms drifting or floating in the sea or fresh water, consisting chiefly of diatoms, protozoans, small crustaceans, and the eggs and larval stages of larger animals" (Plankton, n.d.).

Propagule - "a portion of a plant, fungus, etc., that is capable, when detached, of giving rise to a new individual by asexual or sexual reproduction" (Propagule, n.d.).

Rhizome - "a horizontally creeping underground stem which bears roots and leaves and usually persists from season to season" (Allaby 1992, p. 354).

Saprotroph - "any organism that feeds by absorbing dead organic matter" (Martin and Hine 1999, p. 530).

Sexual reproduction - "a form of reproduction that involves the fusion of 2 reproductive cells (gametes) in the process of fertilization" (Martin and Hine

1999, p. 543).

Sheath - "any long or more or less tubular structure surrounding an organ or part (Cook et al. 1974, p. 554).

Shoot - "the aerial part of a vascular plant... that consists of a stem supporting leaves, buds and flowers" (Martin and Hine 1999, p. 544).

Spadix - "fleshy spike crowded with flowers, usually of Araceae" (Cook et al. 1974, p. 554).

Spathe - "the bract or pair of bracts surrounding or subtending an inflorescence" (Cook et al. 1974, p. 554).

Spore - "small asexual usually unicellular reproductive body" (Cook et al. 1974, p. 554).

Stolon - "a long aerial side stem that gives rise to a new daughter plant when the bud at its apex touches the soil" (Martin and Hine 1999, p. 567).

Thallus - "the entire cellular plant body without differentiation into stems and leaves" (Cook et al. 1974, p. 555).

Thermophilic - "describing an organism that lives and grows optimally at extremely high temperatures, typically over 40 C (104 F)" (Martin and Hine 1999, p. 588).

Tuber - "(plants that) are generally bigger than true corms and bulbs. They have swollen, often irregularly shaped, underground stems... Buds form between the nonfunctioning leaves to produce new shoots and roots" (Mathew and Swindells 1994, p. 9).

Vegetative propagation - "a form of asexual reproduction in plants whereby new individuals develop from specialized multicellular structures (e.g. tubers) that become detached from the parent plant" (Martin and Hine 1999, p. 616).

Vermicomposting - "the use of earthworms to convert organic waste into fertilizer" (Vermicomposting, n.d.).

Viable - "(of a plant, animal or cell) capable of surviving or living successfully" (Soanes 2002, p. 938).

Viticulture - "the study of (or) the cultivation of grapevines" (Viticulture, n.d.).

Limitations

The limitations of this project included the following:

1) Experiments conducted in outdoor settings were subject to various extraneous factors such as weather, animal activity, etc. These extraneous factors could have impacted the results of the study.
2) The composting process occured at the Texas State Bobcat Blend compost facility located outdoors in the Blackland Prairies subregion approximately 4 miles from the Edwards Plateau subregion. These subregions of Texas were subjected to weather and climatic patterns different from the Gulf Coast Prairies and Marshes subregion (Lyndon B. Johnson [LBJ] School of Public Affairs 1978).
3) This project was limited to studying the potential invasive species management using a large-scale composting system of 3 organisms: *Colocasia esculenta* (wild taro), *Sargassum fluitans* and *Sargassum natans* (brown algae, collectively).
4) Given the difficulty in *Sargassum* identification and subsequent manual separation, the harvested species were studied collectively.
5) Additional compost feedstocks consisted of foodwaste and agricultural waste products found in the Blackland Prairies, Edwards Plateau, and/or Gulf Coast Prairies and Marshes subregion(s) of Texas.

6) Harvesting of *Sargassum* was limited to a short time period based on its appearance on the Texas coastline and transportation limitations.

Basic Assumptions

The basic assumptions of this project included:

1) Wild taro (*Colocasia esculenta*) and brown algae (*Sargassum*) would undergo decomposition in the same manner under the same management system, regardless of their harvest site.
2) Random samples of cured compost were accurately screened for all wild taro (*Colocasia esculenta*) and brown algae (*Sargassum*) seeds, rhizomes and additional propagules.
3) All measurement devices used to test compost temperatures, seed mortality, seed viability and propagule growth provided valid and reliable readings.
4) Additional carbon and nitrogen feedstocks used in the compost creation process were consistent in content and readily available in the Blackland Prairies, Edwards Plateau, and/or Gulf Coast Prairies and Marshes subregion(s) of Texas.
5) Random samples collected for quality testing were of overall compost piles.

CHAPTER II

REVIEW OF LITERATURE

Wild Taro (*Colocasia esculenta*)

Description

Wild taro [*Colocasia esculenta* (L.) Schott], a member of the Arum family (Araceae), is an exotic species invasive to the San Marcos River ecosystem (Akridge and Fonteyn 1981, Atkins and Williamson 2008, Gonzalez and Christofferson 2006, Nelson and Getsinger 2000, Nesom 2009). Taxonomically, members of Araceae are referred to as "rhizomatous or tuberous" (F. Oxley, personal communication, May 9, 2012). Wild taro is an emergent aquatic and semi-aquatic perennial herbaceous species that is also commonly referred to as dasheen, coco yam or eddoe. The individual plant reaches a height of 1.2 m with arrowhead-shaped, dark green, velvety leaves that can extend 60 cm long and 50.8 cm wide (Atkins 2006, Atkins and Williamson 2008, Christman 2008, Langeland and Burks 1988, MacDonald et al. 2008, TIPPC 2008). The petiole is attached to the leaf in a peltate arrangement. A purplish circular dot approximately 1 - 2 cm in diameter forms on the top of the leaf where the petiole reaches the underside of the blade (MacDonald et al. 2008). The large, underground, root-like structures are usually oblong and have a brown protective layer with a white or pink center (Christman 2008, Manner and Taylor 2011). They can grow up to a 30.5 cm in length and 3.6 kg in weight (Atkins 2006, Atkins and Williamson 2008, Cook et al. 1974, Christman 2008, Langeland and Burks 1988, MacDonald et al. 2008, TIPPC 2008).

Wild taro leaves and root structures contain a crystalized form of oxalic acid (or crystal calcium oxalate), which accounts for its physical structure, toxicity to wildlife and iritation commonly experienced when the interior of the plant is touched

(Black 1918, Everitt et al. 2007, Gonzalez and Christofferson 2006, Kimmel 2006). When the interior of the plant is brought in contact with water, cells eject individual, fine, needle-like calcium oxalate crystals which accounts for the irritation and toxicity experienced by natural predators and humans (Black 1918).

Wild taro thrives in tropical and temperate regions in freshwater swamps, streambanks, soils marked by high acidity and/or riparian areas with rocky crevices that provide strong footholds (MacDonald et al. 2008, Matthews 2003). Wild taro is well adapted to shady conditions and seems to grow best in silty, anaerobic soils lining the riverbanks, both just above and below the water line (Akridge and Fonteyn 1981, Atkins 2006, Atkins and Williamson 2008).

Wild taro (*Colocasia esculenta*) is commonly mistaken for elephant ear (*Xanthosoma sagittifolium*), a species also invasive to the San Marcos River system (Lemke and Schneider 1988). Elephant ear (*Xanthosoma sagittifolium*) closely resembles wild taro in leaf morphology but can be differentiated by a lighter shade of green leaves, a larger height of up to 2.7 m, a lack of purplish coloration, and the petiole attaching at the base of the leaf margin rather than in a peltate arrangement (Langeland and Burks 1988, MacDonald et al. 2008). This species, while exotic to the U.S., is less invasive and widespread than *Colocasia esculenta* (Lemke and Schneider 1988, MacDonald et al. 2008). Only a few stands of *Xanthosoma sagittifolium* exist in the San Marcos River ecosystem along Spring Lake (J. Poole, personal communication, May 9, 2012).

<u>History</u>

Wild taro (*Colocasia esculenta*) was a crop used at the time of the earliest agricultural practices. Indigenous to the New Guinea and Oceania regions, the starchy roots of cultivars were eaten as early as 6950 to 6440 BP, during the Holocene epoch

(Fullagar et al. 2005, Matthews 2003). Wild taro (*Colocasia esculenta*) was brought to the United States from Africa as a food source for slaves (Akridge and Fonteyn 1981, Greenwell 1947, MacDonald et al. 2008). The United States Department of Agriculture (USDA) introduced wild taro into Florida and other southern states as a potential substitute for potato in 1910 (Atkins and Williamson 2008, Langeland and Burks 1998, MacDonald et al. 2008). From 1914 to 1924, the Texas Agricultural Experiment Station in Angleton experimented using taro as a potato replacement but the project did not yield successful results (Kimmel 2006). Wild taro (*Colocasia esculenta*) was introduced to the San Marcos River ecosystem during the early 1900s (Atkins and Williamson 2008).

Utilization of Wild Taro (*Colocasia esculenta)*

Approximately 100 million people in Africa, the Pacific Basin, Central and South America, Southeast Asia, the West Indies use the roots of cultivars of this plant for basic dietary needs (Atkins and Williamson 2008, Kimmel 2006, MacDonald et al. 2008). Cultivars are commonly propagated in Hawaii, Asia and the Pacific regions (Manner and Taylor 2011, Matthews 2003). The toxic oxalic acid present in the plant is destroyed before consumption by cooking for up to 8 hours at a time (Fullagar et al. 2005). Prajapati et al. (2011) discussed the use of extracts from *Colocasia esculenta* for potential use in the pharmaceutical industry for their anti-inflammatory, cancer-fighting and analgesic properties. Additional research discusses the potential of using wild taro for the recovery of biogas using solid-feed anaerobic digesters (SOFADs) (Bindu and Ramasamy 2005, Bindu and Ramasamy 2008). Wild taro is currently utilized and sold in the United States horticultural industry as an ornamental plant (Everitt et al. 2007, University of Georgia - Center for Invasive Species and Ecosystem Health 2012).

Current Management Practices

The initial steps to ensure *Colocasia esculenta* does not spread are by prevention through education of local citizens and the removal of existing plants (Gonzalez and Christofferson 2006, MacDonald et al. 2008, Nesom 2009). Chemical treatments currently used to manage wild taro can damage local ecosystems and are potentially less effective than alternative means (Atkins and Williamson 2008, Nelson and Getsinger 2000). Atkins and Williamson (2008) assessed 4 techniques for removal of wild taro (*Colocasia esculenta*) to determine which process reduces the most organism biomass and results in the highest level of vegetative growth prevention. The objectives of Atkins and Williamson's project (2008) were to determine which technique would be the most effective for removing/preventing plant growth and limiting human labor costs. Methods included the use of glyphosate herbicide, mechanical cutting, manual removal and a combination of mechanical cutting / herbicide use. Manual removal consisted of "hand pulling the entire plant, including the (rhizome), from the soil" and was the most effective method for wild taro harvesting (Atkins and Williamson 2008, p. 159).

The current management practices in Spring Lake, the headwaters of the San Marcos River, are coordinated by the Meadows Center for Water and the Environment at Texas State University. Practices consist of manual removal and the use of a harvester boat to remove floating plant matter. Organic material of species not identified to be compostable is then disposed of in a landfill (A. Wallendorf, personal communication, November 28, 2011).

Brown Algae (*Sargassum fluitans* and *Sargassum natans*)

Description

Nearly 10,000 different types of seaweed algae thrive in the world’s oceans and seas. These include brown algae (approximately 2,000 species), green algae (approximately 1,200 species) and red algae (approximately 6,000 species) (Wang et al. 2009). Algae in the genus *Sargassum* of the Sargassum family (Sargassaceae) are considered brown algae. Over 150 species of Sargassum are distributed throughout the tropical and temperate oceans throughout the world, thriving in warmer oceans and seas (Abbott and Dawson 1978, Fritsch 1965). Two planktonic species drift en masse onto the shores of the Texas Gulf Coast: *Sargassum fluitans* and *Sargassum natans,* also known collectively as gulfweed, sea holly or Sargassum. This community is a "self-supporting population (that forms) a planktonic community together with its associated epiphytic species" when at sea (Round 1981, p. 296). When on land, Sargassum creates complicated problems for residents along the shoreline. In 2011, *Sargassum fluitans* was added to the Global Invasive Species Database (ISSG 2011).

Sargassum species can be identified by their lateral, branch-like morphology. One or 2 leaf-like structures form at the base of the organism. The thallus and branch structure of the algae grows from this organ (or 1 of them, if 2 are present) (Fritsch 1965). The thallus and blades are generally brown, yellow or gold in color. *Sargassum fluitans* and *Sargassum natans* are marked by tiny, circular bladders (pneumatocysts) that are filled with gas (Conti 2008, Coston-Clements et al. 1991, Rogers 2011). These bladders keep them afloat allowing their blades to photosynthesize. *Sargassum fluitans* can be distinguished from *Sargassum natans* by the presence of winged tissue around the bladder stalk and the lack of spines on bladders (Conti 2008, Shapiro 2004). The 2 species are highly difficult to distinguish from one another once they have arrived on the shoreline (Shapiro 2004).

History

Round (1981) notes that Christopher Columbus first identified *Sargassum* *natans* and *Sargassum fluitans* during his westward 1492 voyage, noting the "small, berry-like bladders on the side branches" of the algae. A major source of historical information of Sargassum presence on the Texas shoreline can be found in newspaper articles mentioning its presence on beaches (Webster 2008). Though assumed by scientists to originate from the Sargasso Sea in the Atlantic Ocean, recent findings from satellite imagery suggest that Sargassum originates in the Gulf of Mexico and then recirculates to the U.S. Atlantic coast (Gower et al. 2006).

Utilization of Brown Algae (*Sargassum fluitans* and *Sargassum natans*)

Sargassum acts as a natural fertilizer for *Panicum amarum*, a grass native to coastal regions that is adapted to saline conditions (Williams 2008). There is also potential for Sargassum to be sold as a flavor enhancer of food products (Chennubhotla et al. 1981, Fox 2008). Algin, a carbohydrate found in Sargassum, is extracted for use in the textile, paper and pharmaceutical industries (Chennubhotla et al. 1981). Sargassum biomass also shows potential to be an important, renewable energy resource via methane production and combustion (Wang et al. 2009, Yokoyama et al. 2007).

Current Management Practices

The Texas beaches include some of the most pristine, primitive coastlines in the world. The Padre Island National Seashore, for example, is the longest stretch of undeveloped barrier island in the country (Biel 2008). The beaches of the Texas coast are maintained by various organizations including federal and state agencies, cities, counties, and private owners. Some areas, such as Galveston Island, are maintained by over 5 different agencies (Williams and Feagin 2007). Although variations exist between the tactics utilized by these organizations, basic beach maintenance objectives include: 1) maintaining safe and sanitary conditions, 2) allowing for the use of recreational activities (e.g. sunbathing, camping, wildlife observation and beach combing), 3) monitoring trash removal, 4) protecting wildlife habitats and 5) limiting the amount of Sargassum on the coastline (Biel 2008, City of Corpus Christi 2011, Conti 2008).

All beach property owners are required to adhere to regulations stipulated by the Open Beach Act (OBA), Dune Protection Act (DPA), Clean Water Act, and Beach Dune (BD) legislation. The Sargassum on beaches is handled using a variety of methods. Front end loaders are allowed access to the shoreline to scrape large amounts of the seaweed and sand, tons at a time in some cases. If small amounts of biomass float onto on the shore, large rakers are used. Some organizations clean the beach completely; others allow small amounts of Sargassum to remain on the shore. When the Sargassum has been loaded, it is placed at the edge of the foredune and allowed to revegetate or placed in temporary holding centers (Conti 2008, Watson 2008). This material is used to create "maintenance dunes" seaward of the natural dunes (Conti 2008). In other cases, the seaweed is dumped back into the ocean (Watson 2008).

Raking is only implemented during the 4 to 6 months of the year when the mats of brown algae 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. At these times, areas to be raked are prioritized based on visitor numbers, holidays and Sargassum amounts on the shore (City of Corpus Christi 2011, Jensen 2008). Some organizations train their employees to identify nesting sites for Kemp's ridley sea turtles (*Lepidochelys kempii*), a critically endangered species. At the Padre Island National Seashore and in the City of Corpus Christi, patrols comb the beaches checking for nests before raking occurs (Biel 2008, City of Corpus Christi 2011).

The Complicated Issue of Raking

Sargassum maintenance is motivated by tourist values and preferences (Smith-Engle 2008). According to Keith Arnold, the CEO of the Corpus Christi Convention Center and Visitors Bureau, tourists expect "prisitine beaches" and view seaweed mats as a "vision of poor beach maintenance." He argues that there is an inverse relationship between seaweed amounts and visitor numbers (Arnold 2008). In local economies that are basically dependent upon tourism dollars, maintaining or increasing tourist numbers is essential (Arnold 2008, Pettis 2008).

Sargassum clean-up is perceived by many as a beautification process. "Nobody likes to see it. Nobody likes to smell it," states Blake Pettis of the Nueces County City and Parks Recreation Department (Pettis 2008). Enormous piles of fresh and partially-dried, smelly seaweed mats are cleared to create a clean, groomed beach (Conti 2008, Smith-Engle 2008, Watson 2008). There is subseqent increased visitor access to the shoreline and areas for tourists to sunbathe, camp and drive (Conti 2008). Additionally, Sargassum maintenance prevents the accumulation of refuse that frequently mixes in with the seaweed creating a "trashy" appearance. The enormous size of these mounds can also deter the nesting of Kemp's ridley sea turtles (*Lepidochelys kempii*) (Smith-Engle 2008).

Although Sargassum can be used to create stabilized maintenance dunes, many coastal areas are running out of beach space due to rising sea levels, erosion and the increasing size of these dunes (Conti 2008, McCutchon 2008, Watson 2008). Additionally, while wider dunes allow better protection from strong storms and increased native vegetation, the walk the visitor makes from the hotel or car to the seashore becomes longer as years pass. The public demands and expects quick and easy access because long walks "impede beach enjoyment" (McCutchon 2008).

However, tourists' values and preferences differ. Many individuals prefer a natural-appearing beach, a space that "facilitates learning about natural coastal processes and sea life" (Smith-Engle 2008). "For some," stated Dr. Jennifer Smith-Engle of Texas A&M University at Corpus Christi, "the opportunity to gaze on fresh *Sargassum* strewn thickly along the coast as far as eyes can see is more important than a scraped and manicured beach." Many of the attendees of the 2008 Sargassum Symposium such as Chuck Cazales, a Nueces County Commissioner, told anecdotes of exploring the Sargassum with his/her children, searching for the community of creatures living in the fresh gulfweed. The fresh mats provide exactly that: Sargassum is a source of food and/or shelter for various species of crustaceans, worms, insects, shorebirds and gulls. Research shows that weekly raking prevents these organisms from recovery (Withers 2008). Though piles of Sargassum may deter sea turtle nesting, the front end loaders and additional heavy machinery also threaten turtle communities (Smith-Engle 2008).

The natural, unaltered process of Sargassum mat formation also allows dried seaweed to blow naturally onto foredunes creating more stable, rejuvenated dunes by allowing pioneer species to take root (Biel 2008). Also, Texas coastal communities are running out of space for maintenance dunes. A wide section of dry beach is needed for dune growth and in some locations the beach width is extremely narrow (Watson 2008). It is also argued that the removal of Sargassum (and more importantly, the sand) from the shoreline alters long-term beach profiles and increases beach erosion following storms (Conti 2008). One study revealed no direct connection between raking and long-term influences on beach morphology, but recommends more research be completed in this area (Webster 2008). Finally, some aspects of the use of heavy machinery on the shoreline is in direct conflict with the Open Beach Act and Dune Protection Act (Conti 2008).

A challenging, complex situation exists among the connections between the environmental, social, cultural and economic concerns of Sargassum mats. At the 2008 Sargassum Symposium, Keith Arnold, CEO of the Corpus Christi Convention Center and Visitors Bureau, argued that nature and economy are inherently linked: the local economic sector will not thrive without natural resources and the environment will not survive if not financially supported by private industry (Arnold 2008). The consensus of the 2008 Sargassum Symposium recognized the need for increased education of the tourist and local population, altering current management practices and supporting additional research on alternative uses for Sargassum (Arnold 2008, Conti 2008, Walker 2008, Smith-Engle 2008). The decreasing amount of beach space is a shared concern and, subsequently, removal of Sargassum is still an important option for beach maintenance. Composting should be evaluated as an alternative use for the biomass.

Compost

The Composting Process

Composting is a biomechanical process during which microorganisms such as bacteria and fungi convert organic matter into a waste-free, soil-like product called compost (Rynk 1992). The mechanical manipulation increases the rate of decomposition that occurs in natural environments (Pennsylvania State University 2012). Compost is created by constructing piles to form an ideal C:N ratio (carbon: nitrogen ratio) of 30:1. Carbon (or "browns") include dried organic matter such as dried leaves, cardboard and paper while nitrogen (or "greens") include organic materials such as food waste, plant clippings, green yard waste or manure. Aerobic decomposition of these materials occurs via microorganisms which feed on the organic matter as long as the ratio of materials is balanced, water supply is sufficient and temperatures are kept warm enough to allow the thermophilic organisms to survive (Darlington 2007, Dougherty 1999, Rynk 1992). Composting can take as little as 2 weeks to over 1 year to complete, depending on the amount of human intervention, types of feedstocks used and weather conditions (Pennsylvania Department of Environmental Protection [PDEP] 2012). Mature compost has little resemblance to the feedstocks used in its creation.

The creation of compost includes 2 phases: the active stage and the curing stage. The active stage begins as soon as the feedstocks are thoroughly blended, allowing enough air to enter the pile for microorganisms to begin consuming oxygen and producing carbon dioxide (Dougherty 1999). Temperatures quickly rise to approximately 49 C to 60 C and remain at this temperature range for at least 3 weeks. The ratio of materials, moisture content, oxygen content, pH and temperatures must be monitored during this process to ensure the thermophilic organisms survive (Darlington 2007, Dougherty 1999, Rynk 1992). Techniques used to maintain large-scale processes include rotating piles and maintaining sufficient irrigation. The curing stage is "the last stage of the composting process that occurs after most of the organic feedstock material has been decomposed and stabilized" (Dougherty 1999, p. 15). When the temperatures throughout the pile drop to approximately 38 C and begin to stabilize, the curing process has begun. Compost must cure for at least 1 month in order to prevent phytotoxins from entering the soil and to minimize the amount of nitrogen and oxygen that is trapped in the soil (Dougherty 1999).

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). The use of compost also "encourages healthy plants that are better equipped to fight off disease" by increasing the number and diversity of microorganisms and enhancing beneficial chemical and physical properties of the soil (Compost for Soils 2009, p.1). Properly created compost consists of a large amount of carbon-based materials that release nitrogen, phosphorus and potassium into the soil slowly over time, providing plants with a sustained defense against diseases and eliminating the use of fertilizers (Compost for Soils 2009, Dougherty 1999, Rynk 1992). An additional benefit of composting relies on the sustained, high temperatures reached during the active stage. If high temperatures of 49 C to 82 C are sustained for a period of time (3 to 7 days), various types of weed seeds and additional propagules will be left inviable, including field bindweed (*Convolvulus arvenssis*), Georgia cane (*Arundo donax*), hydrilla (*Hydrilla verticillata*), johnsongrass (*Sorghum jalapense*), pigweed (*Amaranthus* spp.), water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) (Meier 2011, Montoya et al. 2013, Wiese et al. 1998).

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 products and byproducts currently used include compost tea, vermicomposting and the use of biogas digesters to create clean energy (Ganesh et al. 2005, Scheuerell and Mahaffee 2002).

Composting Wild Taro (*Colocasia esculenta*)

Studies in India have highlighted the potential of using ground wild taro to yield clean energy in the form of methane biogas (Bindu and Ramasamy 2005, Bindu and Ramasamy 2008). *Colocasia esculenta*, considered an environmental nuisance, pollutant and invasive species in India, was treated as a potential resource with high amounts of carbon, nitrogen and phosporus that could be used to increase soil quality and/or produce clean energy in the form of methane. Vermicomposting has also been used to successfully break down the biomass remnants following methane production (Bindu and Ramasamy 2005, Kurien and Ramasamy 2006). In all studies with wild taro, biomass was air-dried and chopped into pieces 2-3 cm in length. No studies attempted to compost using the bulbous, starch-filled structures of the plant or from non-treated taro (Bindu and Ramasamy 2005, Bindu and Ramasamy 2008, E.V. Ramasamy, personal communication, May 10, 2012, Kurien and Ramasamy 2006).

Composting Brown Algae (*Sargassum fluitans* and *Sargassum natans*)

Seaweed and its products have been used for centuries to enhance plant growth and productivity, particularly in coastal Asia (Eyras et al. 2008, Win and Saing 2008). Seaweed algae has physical and chemical attributes useful for plant health, root growth, increasing plant yield, increasing seed germination and enhancing plant resistance to disease (Dougherty 1999, Eyras et al. 2008, Win and Saing 2008). Though liquid seaweed, seaweed extract, foliar spray and seaweed meal are highly valued by horticultural and agricultural markets as an additive with nutrient properties that safely enhance vegetative growth, the literature on composting and horticultural uses of *Sargassum fluitans* and *Sargassum natans* is limited (Chennubhotla et al. 1981, Klock-Moore 2000, Win and Saing 2008). According to Jason Pinchback, the Director of Planning, Permitting, and Technical Services for the Coastal Resources Division of the Texas General Land Office (GLO), no previous studies have examined utilizing *Sargassam natans* or *Sargassum fluitans* along the Gulf Coast as a feedstock for compost creation (J. Pinchback, personal communication, May 31, 2012).

Composting seaweed has also been utilized to minimize the effects of pollution by creating a valuable product for the horticultural or agricultural consumer (Eyras et al. 2008). The benefits of compost created from additional species of algae have had mixed results chiefly due to the salinity of the final product and the types of plants on which the compost is tested (Eyras et al. 2008, Klock-Moore 2000). Regardless, compost created from ocean algae consistently has a slightly higher pH and lower nitrogen content when compared to compost from traditional feedstocks, but still creates a valuable product available to enhance soil and plant properties while preventing pollution (Eyras et al. 1998, Maze et al. 1993).

The average amount of soluble salt content or electrical conductivity (EC) in finished compost is 1 to 30 dS/m (decisiemens per meter) or 1 to 10 mmhos/cm (millimhos per centimeter) (Darlington 2007, Dougherty 1999, US Composting Council 2002). Different types of plants have varying salt content tolerances: most vegetable and fruit plants can tolerate a maximum salt concentration of 1 to 6 dS/m; most turf species can tolerate 1 to 4 dS/m while ornamentals can tolerate up to 1 to 3 dS/m (US Composting Council 2001). Excessive salinity amounts can be toxic to plants. High salinity can prevent or delay seed germination, impair root growth, increase plant susceptability to disease, prevent the disease suppression qualities of low salinity compost and decrease the quality of soil structure and water holding capacity (Dougherty 1999, Compost for Soils 2009, Compost for Soils 2011, Hoitink and Rynk 2000, US Composting Council 2002). The effects of salinity in soils can be counteracted with leaching and/or the application of high-quality, organic-rich, low-salinity compost, gypsum, lime and organic matter (Compost for Soils 2009).

Compost created from saline feedstocks (e.g. oceanic algae) must be carefully controlled and monitored for proper EC (Dougherty 1999, Eyras et al. 2008). Salinity levels of compost may exceed salinity tolerances of many plants, but can be reduced to acceptable levels by proper treatment. Previous studies have used substantial irrigation to wash away the soluble salt content before or during the compost process

(Eyras et al. 1998, Eyras et al. 2008). 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 when compared to compost aged for 9 months. Also, feedstocks of high salinity can be combined with low salinity feedstocks to dilute the final product (Dougherty 1999). Finally, actively turning the piles (rather than leaving them static) has been shown to increase the rate of compost creation while decreasing the level of salinity (Dougherty 1999, Eyras et al. 2008).

CHAPTER III

METHODS

Purpose

This project examined large-scale compost management of 3 aquatic species: *Colocasia esculenta* (wild taro), *Sargassum fluitans* and *Sargassum natans* (brown algae, collectively). Each species posed threats to local ecosystems in Texas. This study investigated whether compost management systems offered an effective alternative system of management by rendering the seeds and additional propagules of these species unviable, while creating a marketable byproduct for use in agriculture, horticulture and related markets.

Objectives

The objectives of this study included (1) identifying invasive or problematic species with widespread distribution in Texas that posed a threat to local ecosystems, (2) understanding how each species grew, propagated and functioned in local plant and wildlife communities, (3) evaluating if the natural compost process effectively killed seeds and other propagules as well as eliminated potentially high levels of salinity and (4) determining if large-scale compost management of these organisms offered an effective alternative to current management systems while creating safe, marketable products for the agricultural and horticultural consumer.

Location

This project involved coordination with the Meadows Center for Water and the Environment at Texas State University for permission to harvest wild taro (*Colocasia esculenta*) from Spring Lake, San Marcos, TX. This research also involved work with the City of Corpus Christi and the US Army Corps of Engineers for access to brown algae (*Sargassum fluitans* and *Sargassum natans*). Compost treatments and creation were conducted at the Bobcat Blend compost site, approximately 10 miles from the main Texas State University campus in San Marcos, TX.

Harvesting Wild Taro

Wild taro (*Colocasia esculenta*) biomass was harvested by the researcher, Bobcat Blend staff, volunteers and a trained staff member provided by the Meadows Center for Water and the Environment at Texas State University. The Meadows Center lent all necessary river and boating equipment. All stands of *Colocasia esculenta* were obtained from the shoreline of Spring Lake, the headwaters of the San Marcos River, between the Saltgrass dock and the the storm drain that empties into Spring Lake off of Ed J. L. Green Drive. Plants were harvested via Atkins and Williamson's (2008) method for manual removal. Stands of *Xanthosoma sagittifolium* were identified according to the literature and were not harvested (Langeland and Burks 1988, MacDonald et al. 2008).

Regardless of terminology used to describe wild taro morpohology, the literature agreed that *Colocasia esculenta* had the capacity to spread rapidly and usually propagated asexually. Given that disturbance and accidental dispersal of vegetative fragments may result in proliferation of the species, care was taken to ensure all plant fragments were collected. The US Fish and Wildlife Service oversaw measures used to protect federally endangered species and condoned the management practices used by employees of the Meadows Center to manage invasive species while protecting endangered wildlife (A. Wallendorf, personal communication, July 18, 2012). Trained staff from the Meadows Center ensured these practices were used during the harvesting of taro to protect 2 endangered species that lived along the edge of Spring Lake: the fountain darter (*Etheostoma fonticola*) and San Marcos salamander (*Eurycea nana*) (A. Wallendorf, personal communication, April 23, 2012).

A total of approximately 25 cubic yards of entire wild taro plants, including underground root-like structures, stems and leaves, were collected in a total of 30 hours. The plants were placed in 363.4 L buckets and transported to the Texas State University Bobcat Blend compost site. Three cubic yards underwent different treatments and were used as feedstock in 6 compost piles, which created a need for approximately 18 cubic yards total. The remaining approximate 7 cubic yards were used for morphological identification and viability testing in the Agriculture laboratory at Texas State University. Similar biomass amounts were harvested in related studies studying composting as a management system for invasive species (Meier 2011, Montoya et al. 2013).

Field data categories included:

1) Name and location of collection site.
2) Name of researcher.
3) Date and time of data collection.
4) Environmental conditions during data collection.
5) Documentation of equipment used for sample collection.
6) Name, amount, condition and description of samples collected.

<u>Harvesting Brown Algae</u>

Removal of *Sargassum* biomass from the shoreline and placement into vehicles for transportation to San Marcos, TX was supervised by the City of Corpus Christi according to the permit established by the US Army Corps of Engineers and the City of Corpus Christi Beach adaptive management plan (City of Corpus Christi 2011, D. Herzog, personal communication, May 31, 2012, H. Mullins, personal communication, May 29, 2012). Over the span of 2 days, a total of appoximately 18 cubic yards of "fresh" *Sargassum* (seaweed that arrived on the shoreline during the previous 24 hours) was collected by employees of the City of Corpus Christi to ensure proper procedures were followed. No tar was visible along the shoreline. The plants were transported by trained Bobcat Blend employees from Corpus Christi, TX to the Bobcat Blend compost site 10 miles from the Texas State University main campus in San Marcos, TX. Three cubic yards underwent different treatments and were used as feedstock in 6 compost piles, creating a need for approximately 18 cubic yards total. Similar biomass amounts were harvested in related studies studying composting as a management system for invasive species (Meier 2011, Montoya et al. 2013).

Field data categories included:

1) Name and location of collection site.
2) Name of researcher.
3) Date and time of data collection.
4) Environmental conditions during data collection.
5) Documentation of equipment used for sample collection.
6) Name, amount, condition and description of samples collected.

Viability Tests

Before compost management began, the researcher conducted the following laboratory tests to identify the ideal environment for successful wild taro (*Colocasia esculenta*) propagation and to identify the temperatures required to result in mortality of the plant propagules: growth tests and oven kill tests. Seeds were sought but were not expected to be found, due to the rarity of seed production among wild taro (Langeland and Burks 1988, MacDonald et al. 2008, The University of Georgia - Center for Invasive Species and Ecosystem Health 2012). Growth and oven kill tests were not performed on *Sargassum fluitans* and *Sargassum natans* because brown algae were inviable upon arrival in San Marcos due to the absence of saline water, constant water flow and appropriate temperatures (Abbott and Dawson 1978, Fritsch 1965, Round 1981).

Rhizomes and additional potential propagules from wild taro (*Colocasia esculenta*) were collected and separated by the researcher. Propagules were kept moist, planted in containers filled with fresh potting soil and placed in the Texas State University Agriculture greenhouse prior to testing. If propagules were not immediately processed, they were kept moistened and stored in a cool space to allow for continued growth.

Laboratory data categories included:

1) Name and location of laboratory test.
2) Name of researcher.
3) Date and time of data collection.
4) Environmental conditions during data collection (e.g. internal temperature of incubation chamber).
5) Documentation of external equipment used for sample collection.
6) Container identification number.
7) Number of propagules per container.
8) Number and length of propagule growths per container.

<u>Wild Taro Growth Tests</u>

Literature described the portions of *Colocasia esculenta* necessary for successful plant propagation and their ability to thrive in various environments (Akridge and Fonteyn 1981, Atkins and Williamson 2008, Manner and Taylor 2011). Only a portion of the crown of the (rhizome) and petiole was necessary for wild taro propagation (Christman 2008, Langeland and Burks 1988, MacDonald et al. 2008, Manner and Taylor 2011). Manner and Taylor (2011) recommended a commercial propagation technique using the "top 1 cm of the (rhizome) and about 20 to 50 cm of the petiole" (p. 10). *Colocasia esculenta* was also occasionally propagated from budding at the base of the plant or from a portion of the top of the (rhizome) without the petiole attached (Christman 2008).

A total of 180 propagules were subjected to growth tests. Before the tests began, 50% of the harvested wild taro biomass was dried for 60 days on a concrete block at the Texas State University Bobcat Blend compost site before being subjected to growth tests. Thirty dried rhizomes within each of the following various size ranges were tested for growth: 0.1 cm to 5.0 cm, 5.1 cm to 10.0 cm and 10.1 cm to 15.0 cm (Table 1). Before the test, the following data were documented: intial size of the dried rhizome and the presence or lack of a petiole remnant.

TABLE 1. Wild taro (*Colocasia esculenta*) growth tests conducted on turgid and dried rhizomes in size in the study of using large-scale composting as an alternative means to manage invasive species.

Group	Size	Total
Turgid Rhizome (Whole with 20 to 50 cm of the petiole attached)	Approximately 20.1 cm to 50 cm	30
Turgid Rhizome (Top 1 cm of rhizome attached to the petiole)	Approximately 1.0 to 20.0 cm	30
Turgid Rhizome (Top 1 cm of the rhizome without petiole attached)	Approximately 1 cm	30
Dried Rhizome (Small)	Approximately 0.1 to 5.0 cm	30
Dried Rhizome (Medium)	Approximately 5.1 to 10.0 cm	30
Dried Rhizome (Large)	Approximately 10.1 to 15.0 cm	30
Total		180

The remaining 50% of the wild taro biomass was not dried and subsequently identified as "turgid." These 90 "turgid" wild taro propagules were sorted and evaluated based on propagule size (Table 1). Before each growth test, the following data were documented for each plant: size of the rhizome, total plant size as well as the number of roots and leaves.

Propagules representing each size were chosen randomly from the harvested samples by the researcher and were placed in sterilized 3.78 L containers with fresh potting soil (Sunshine Mix 1, Sun Gro Horticulture, Agawam, MA) and moistened with distilled water to replicate their submerged aquatic environment. Containers were placed in the Texas State University Agriculture greenhouse. Samples were monitored daily during testing to ensure the propagules remained submerged and that temperatures remained around 26.7 C, the ideal temperature for wild taro propagation (Manner and Taylor 2011). Propagules were held in the greenhouse for a total of 14 days to allow for growth (Manner and Taylor 2011, Meier 2011). Temperatures remained within the range for optimal wild taro growth: the lowest average temperature was 16.1 C while the highest average temperature was 32.4 C. After testing, data were analyzed to determine the size and type of propagule necessary for

Colocasia esculenta growth and propagation.

Wild Taro Oven Kill Tests

Oven kill tests were used to mimic conditions in active composting piles and identify the average temperature wild taro (*Colocasia esculenta*) propagules were rendered inviable. According to Atkins and Williamson (2008), "only a portion of the (rhizome) crown and petiole (were) needed to establish a new plant" (p. 159). Manner and Taylor (2011) noted that wild taro (was) commercially produced in Hawaii "from mature (rhizomes) and consist(ed) of the top 1 cm of the rhizome and about 20 to 50 cm of the petiole" (p. 10). A total of 270 propagules were subjected to oven kill tests. Tests utilized 15.2 cm wide terra cotta containers filled with manufactured compost and wild taro propagules subjected to 3 different treatments described in Table 2.

TABLE 2. Wild taro (*Colocasia esculenta*) oven kill tests conducted on turgid, whole rhizomes with 20 to 50 cm of the petiole attached, the top 1 cm of the rhizome attached to the petiole or the top 1 cm of the rhizome without petiole attached in the study of using large-scale composting as an alternative means to manage invasive species.

Group	Size	Oven 1: 45 C - 52 C	Oven 2: 53 C - 61 C	Oven 3: 62 C - 71 C	Total
Whole rhizomes with 20 to 50 cm of the petiole attached	Up to 0.5 m	30	30	30	90
Top 1 cm of rhizome portion attached to the petiole	Approximately 1.0 to 20.0 cm	30	30	30	90
Top 1 cm of the rhizome portion without petiole attached	Approximately 1 cm	30	30	30	90
Total					270

All propagules for the tests were chosen randomly from the harvested samples by the researcher. The oven kill tests utilized 6 ovens located in the Texas State University Agriculture building (Model 10AF, Quincy Lab, Chicago, IL). The day before the tests, 16.5 cm terra cotta containers of compost were placed into ovens at various temperatures so the compost could adjust to the assigned temperatures. Preparation included "sterilizing all equipment, adding the compost samples moistened with distilled water to each soil sample container, weighing each container, pre-labeling each container, placing containers in the appropriate oven, and then turning on the oven" (Meier 2011, p. 79). Each oven was turned on the day before so that the desired temperature could be achieved and sustained before the propagules were added to the containers. Propagules and distilled water were added to the compost samples the day of the test to compensate for water loss during initial heating.

Wiese et al. (1998) determined that seeds of various weed grasses including field bindweed (*Convolvulus arvenssis*), johnsongrass (*Sorghum jalapense*) and pigweed (*Amaranthus* spp.) could be rendered inviable at temperatures between 49 C to 82 C and could be killed within 3 days. Additional research has shown that invasive propagules of Georgia cane (*Arundo donax*), hydrilla (*Hydrilla verticillata*), water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) could also be rendered inviable according to the same methods (Meier 2011, Montoya et al. 2013). Ten propagules of *Colocasia esculenta* at various stages of maturity and/or treatment were subjected to oven temperatures for 3 days (Meier 2011). The oven kill tests were repeated 3 times to ensure reliability and validity. To test for propagule mortality, ovens tests included propagules from wild taro (*Colocasia esculenta*) held at average temperatures within the following ranges: 45 to 52 C, 53 to 61 C and 62 to 71 C (Table 2).

Oven temperature, substrate temperature, container moisture level and humidity level were checked each day and adjusted if necessary (General-Purpose Mercury Laboratory Thermometer, Fisher Scientific, Pittsburgh, PA). Distilled water was used to maintain a moisture level in the substrate of 50 to 70% to maintain the viability of the compost (Rynk 1992). After 3 days of oven temperatures, propagules were screened from the compost. If a propagule showed any sign of viability (i.e. turgidity, lack of odor, root growth or lack of color change), the sample underwent post-oven kill growth tests for a 14 day period to determine viability. Temperatures during post-oven kill growth tests remained within the range for optimal wild taro growth: the lowest average temperature was 15.6 C while the highest average temperature was 42 C.

<u>Compost Pile Recipes and Management</u>

Wild taro (*Colocasia esculenta*) and brown algae (*Sargassum fluitans* and *Sargassum natans*) were manually harvested from the San Marcos River and Gulf Coast beach communities and transported to the Texas State University Bobcat Blend compost site. Compost piles were created at this location, an approximately 5 acre plot of land on the Muller Farm owned by Texas State University. Muller Farm consists of approximately 125 acres. Approximately 2.5 acres are allocated for the compost site and approximately 2.5 acres surrounding the compost site serves as run-off space and a catchment pond that "can withstand a 25 year 24 hour flood event" (Meier 2011, p. 84).

All compost was produced at this location allowing for extraneous sources of error (e.g. weather) to be constant. Each compost pile was monitored to ensure ideal conditions were met for the composting process: using a proper ratio of materials, maintaining a sufficient water supply through weekly thorough irrigation of the piles, proper aeration via weekly pile rotation and allowing for temperatures to reach approximately 62 C to 71 C for a minimum of 3 days. Data were collected every 5 to 7 days and treatments adjusted to maintain these ideals.

Categories of data for each pile included:

1) Name and location of collection site.
2) Name of researcher.
3) Date and time of data collection.
4) Pile identification number.
5) Feedstock percentages.
6) Age of pile.
7) Environmental conditions during data collection.
8) Condition of pile (i.e. average pH, average temperature, average moisture content, average oxygen content and presence of odor).
9) Treatment applied to pile, if necessary (e.g. irrigation, pile rotation, etc).
10) Documentation of equipment used for pile monitoring and treatment.

A total of 12 piles approximately 1.8 m in height and 3 m in length were created. Each pile contained 12 cubic yards of feedstocks including wild taro (*Colocasia esculenta*) and brown algae (*Sargassum fluitans* and *Sargassum natans*) separately, food waste from cafeterias at Texas State University and wood chips produced and donated by Bartlett Tree Company. All contents were calculated, recorded and documented.

The percentage of feedstocks remained the same for all 12 piles, but the treatment of the invasive species varied to determine the rate of decomposition and compost formation, if all treatments rendered the propagules of the invasive species inviable and the most effective method to minimize salinity in piles created with brown algae. All individual plants used in the piles were chosen randomly from the harvested samples by the researcher to be used in piles. Three piles each containing 12 cubic yards were created following each of the recipes shown in Table 3.

TABLE 3. Four compost pile recipe percentages and total cubic yards using 2 invasive species subjected to different treatments including dried wild taro (*Colocasia esculenta*), turgid wild taro (*Colocasia esculenta*), treated brown algae (*Sargassum* spp.) and non-treated brown algae (*Sargassum* spp.) in the study of using large-scale composting as an alternative means to manage invasive species.

Group	Food Waste	Wood Chips	*Colocasia esculenta*	Treatment of species	Total Pile Number and (Amount)
A	25%	50%	25%	Dried	3
Amount	3 yards	6 yards	3 yards	Dried	(12 yards)
B	25%	50%	25%	Turgid	3
Amount	3 yards	6 yards	3 yards	Turgid	(12 yards)
Group	Food Waste	Wood Chips	*Sargassum* spp.	Treatment of species	Total Pile Number and (Amount)
C	25%	50%	25%	Treated	3
Amount	3 yards	6 yards	3 yards	Treated	(12 yards)
D	25%	50%	25%	Non-treated	3
Amount	3 yards	6 yards	3 yards	Non-Treated	(12 yards)
				Total Pile Number and (Amount):	12 (144 yards)

Before the wild taro was placed into piles, 50% of the harvested wild taro biomass was dried for 60 days on a concrete block. The remaining 50% was not dried and identified as "turgid" when placed into the compost piles. Before the Sargassum was placed into piles, 50% of the harvested brown algae biomass underwent a treatment of being manually washed with tap water and screened through a charcoal fiberglass screen wire to remove as much tar, salt and sand as possible. Although tar was not noticeable on the Corpus Christi shoreline, tarballs were identified sporadically when washing the seaweed. These tar balls occured due to "natural seepage from the ocean floor" and were "considered a part of the natural ecosystem" (D. Herzog, personal communication, July 8, 2013). All trash and tar balls 2 cm or larger were manually removed from the biomass. The remaining 50% of the seaweed was not washed and identified as "non-treated" when placed into the compost piles.

Each compost pile was monitored weekly to ensure ideal conditions were met for the composting process and to allow for temperatures to reach approximately 62 C to 71 C for a minimum of three days during the active stage to ensure that all propagules were exposed to the temperatures used in the oven kill tests. Piles were tested to ensure each pile maintained the ideals suggested in the *Field guide to on-farm composting* (Dougherty 1999). Every 5 to 7 days, 5 readings were taken from areas in the 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 above 62 C for a minimum of 3 days (Super Duty - Fast Response Windrow Compost Thermometer, Reotemp Instrument Corporation, San Diego, CA). Temperatures of 62 C or above was chosen as the ideal temperature to mimic oven kill tests and kill pathogens. Piles were monitored and remained in the active state until piles showed the following signs of curing: a lack of foul odor, a lowering and stabilization of temperature, structural consistency and a stabilization of pH. Piles were then allowed to cure for 4 to 8 weeks to complete the composting process (Dougherty 1999, Rynk 1992).

Compost Quality and Testing

After the curing stage of the composting process was complete, samples from throughout each of the piles were collected to create composite subsamples, as described by the Agricultural Analytical Services Laboratory at Pennsylvania State University (2002). Testing was conducted by the researcher as well as the US Composting Council's Seal of Testing Approval (STA) Program. For each test, subsamples of compost were collected from "5 locations around (each of) the pile(s) and from 3 depths at each location" (Pennsylvania State University 2002, p. 1).

Laboratory Screening Tests

These tests were conducted by the researcher and evaluated whether high temperatures reached via composting rendered all wild taro (*Colocasia esculenta*) propagules inviable. The tests adhered to the designated procedures for sampling for compost quality sampling (Pennsylvania State University 2002). These tests were not performed on piles containing Sargassum, because the brown algae were inviable due to the absence of saline water, constant water flow and appropriate temperatures (Abbott and Dawson 1978, Fritsch 1965, Round 1981). Subsamples of 3.78 L were collected randomly from 5 locations at 3 depths for each of the 6 piles created with *Colocasia esculenta* as a feedstock. Material from each of the 3 piles with *Colocasia esculenta* subjected to different treatments were combined to create composite samples, totaling 2 final composite samples of 170.3 L of compost each (Meier 2011, Montoya et al. 2013, Pennsylvania State University 2002).

After the samples were gathered from the Texas State University Bobcat Blend compost site, each composite sample was sifted through a 1.27 cm screener to identify remaining propagules. Wild taro propagules that had not decomposed were subjected to growth tests as described previously (Meier 2011).

Categories of compost data collection included:

1) Name(s) and location(s) of test site(s).
2) Name of researcher.
3) Date and time of data collection.
4) Composite sample identification number.
5) Environmental conditions during data collection (e.g. internal temperature of incubation chamber).
6) Documentation of external equipment used for sample collection (e.g. beaker).
7) Container identification number.

8) Number of propagules per container.

9) Number and length of propagule growths per container.

Quality Tests

In addition to the independent testing completed by the researcher, 4 composite samples were sent to the Compost Tests for US Composting Council’s Seal of Testing Approval (STA) Program at Pennsylvania State University for analyses. Each 1.9 L composite sample included compost from each type of pile created: 1) *Colocasia esculenta* (dried), 2) *Colocasia esculenta* (turgid), 3) Sargassum (treated) and 4) Sargassum (non-treated). Sampling methods were conducted according to the procedures delineated by the US Composting Council's quality testing standards as outlined in the Test Methods for the Examination of Composting and Composts document (Pennsylvania State University 2002, US Composting Council 2002).

These tests evaluated whether treatment methods on piles rendered the final compost product safe and valuable. The tests analyzed compost for quality characteristics, including: pH, soluble salt content or electrical conductivity (EC), moisture content, organic matter content, total nitrogen, total carbon, carbon to nitrogen (C:N) 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 2011, Montoya et al. 2013, Pennsylvania State University 2002, US Composting Council 2002).

The pH is a measurement of the active acidity / alkalinity or hydrogen ion concentration in the compost (US Composting Council 2001). The pH readings were taken from a slurry of compost and deionized water at a 1 to 5 ratio created from each sample. The slurry was then shaken at room temperature for 20 minutes, allowing all salts to dissolve. The pH measurement was then measured from this mixture with an electronic pH meter. However, pH readings were "not a measure of the total acidity or alkalinity and cannot be used to predict the effect of compost on soil pH" (US Composting Council 2002, p. 2). The soluble salts amount (electrical conductivity) was also measured from a slurry of compost and deonized water at a 1 to 5 ratio and measured in millimhos per centimeter (Montoya et al. 2013, US Composting Council 2002).

To obtain the percent moisture and solid readings, compost samples were weighed, dried at 70 (±5) C and re-weighed. The second weight determined percent solids and the evaporated weight determined percent moisture. The percent organic matter was measured using the Loss on Ignition Organic Matter Method by "quantifying the amount of solid material combusted relative to the original oven dried sample" (Montoya et al. 2013, p. 4). Total nitrogen includes all forms of nitrogen: organic nitrogen, ammonium and nitrate. In stable compost, most nitrogen is immediately available for plant absorption. Total nitrogen was calculated using the Total Kjeldahl Nitrogen Semi-Micro Kjeldahl technique. Total carbon was analyzed using the CO^2 Detection Method. This method uses a carbon analyzer (Leo CR-12), combustion, water vapor and an infrared detector to determine the total amount of carbon dioxide produced in the compost sample (Montoya et al. 2013, US Composting Council 2002). The total oxide forms of phosphorus and potassium amounts were also measured but no ideal amount for plant availability has been established (US Composting Council 2002).

Bioassay tests and respirometry (CO^2 evolution) were used to measure the stability and maturity of the compost samples. Bioassay tests analyzed seedling emergence and vigor to identify potential phytoxin presence. Respirometry was used to measure the relative amount of microbial activity (stability) in the samples (US Composting Council 2002). To ensure created compost is stable and mature, piles were cured for a minimum of 4 weeks (Rynk 1992).

Data Analysis

Frequencies and descriptive data were reported at each stage of the project. Previous related studies did not require more extensive data analyses because the propagules were identified as either present or not-present and compost samples were identified as either quality or not quality (Meier 2011, Montoya et al. 2013).

CHAPTER IV

RESULTS

Purpose

The purpose of this project was to evaluate the potential to manage the invasive species wild taro (*Colocasia esculenta*) and brown algae (*Sargassum fluitans* and *Sargassum natans*) in Texas using a large-scale composting system.

Objectives

The objectives of this study included (1) identifying invasive or problematic species with widespread distribution in Texas that posed a threat to local ecosystems, (2) understanding how each species grew, propagated and functioned in local plant and wildlife communities, (3) evaluating if the natural compost process effectively killed seeds and other propagules as well as eliminated potentially high levels of salinity and (4) determining if large-scale compost management of these organisms offered an effective alternative to current management systems while creating safe, marketable products for the agricultural and horticultural consumer.

Identification of Invasive Species

The researcher spoke with staff at the Meadows Center for Water and the Environment at Texas State University, staff at the LBJ Wildflower Center in Austin, TX, employees at the Texas General Land Office (GLO) and other experts in the field to determine species of interest. The researcher also conducted a literature review to narrow down and choose the species of interest for this project.

Wild Taro (*Colocasia esculenta*)

Usually dispersed by purposeful or accidental spread of vegetation fragments, extensive stands of wild taro live in a variety of riparian habitats and are superior competitors against native species (Atkins and Williamson 2008, Gonzalez and

Christofferson 2006). Staton (1992) highlighted the competitive edge of wild taro in his study that showed a 33% increase in frequency, occupying 16.1% of a total area over a period of 16 years. Wild taro reduces biological diversity, both along the shoreline and underwater, by growing prolifically and displacing native plants (Akridge and Fonteyn 1981, Atkins and Williamson 2008, MacDonald et al. 2008, Nelson and Getsinger 2000). It also prevents light from reaching submerged species below the leaf cover, increases the rates of evapotranspiration and offers little value to local wildlife (Atkins and Williamson 2008, Everitt et al. 2007). The presence of crystalized calcium oxalate in the leaves, stems and root structures allow for no natural predation in the United States, increasing its ability to outcompete native species (Atkins 2006).

The Texas Commission on Environmental Quality (TCEQ) lists the plant as a "Species of Concern" and the Texas Parks and Wildlife Department (TPWD) lists the plant as an exotic species requiring management (Atkins and Williamson 2008, Gonzalez and Christofferson 2006). Nesom identifies *Colocasia esculenta* as an F1 Invasive in the Fundamental Invasiveness Index, identifying the plant as "invasive in both disturbed and natural habitats, negatively affecting native species or natural biodiversity by altering native vegetation and habitats or by outcompeting or hybridizing with native species or, invasive into agricultural habitats and causing significant damage" (Nesom 2009, p. 971).

Wild taro is identified as a problematic invasive species in freshwater regions of Texas, Mississippi, Alabama, Louisiana, Florida, North Carolina, South Carolina, Georgia, and Pennsylvania as well as Puerto Rico, Jamaica and India (Atkins and Williamson 2008, Bindu and Ramasamy 2007, Everitt et al. 2007, Gonzalez and Christofferson 2006, Kurien and Ramasamy 2005, MacDonald et al. 2008, TIPPC

2008). The Florida Exotic Pest Council lists *Colocasia esculenta* on its "Invasive plant list" (Hurst 2011). Wild taro has been shown to eliminate native species in Florida (Atkins and Williamson 2008, Hurst 2011).

Wild taro now "forms dense stands and dominates many areas previously uninhabited by native vegetation" along the edge of the San Marcos River (Atkins and Williamson 2008, p. 158). The San Marcos River is a unique river system that is fed by over 200 closely-spaced spring openings along the bottom of Spring Lake, producing the second highest spring discharge in Texas (Brune, 1981, Groeger et al. 1997). Fed by the San Antonio portion of the karstic Edwards Aquifer along the southern and eastern edges of the Edwards Plateau, the San Marcos River maintains dependable flow, constant temperatures, environmental constancy and deeper areas due to dam construction. These factors allow for the proliferation for a number of invasive species, including wild taro (Atkins and Williamson 2008, Kimmel 2006, Groeger et al. 1997, Owens 2001).

In 2001, Owens et al. argued that nearly 80% of the native shoreline aquatic plants along the San Marcos River had been replaced by exotic species. The headwaters of the San Marcos River is home to a number of endangered species including the Comal Springs riffle beetle (*Heterelmis comalensis*), the fountain darter (*Etheostoma fonticola*), the San Marcos gambusia (*Gambusia georgei*), San Marcos salamander (*Eurycea nana*) and the Texas blind salamander (*Eurycea rathbuni*) (A. Wallendorf, personal communication, April 23, 2012, Atkins 2006). The sole habitat of the federally listed endangered Texas wild rice (*Zizania texana*) is a submerged area at the headwaters of the San Marcos River. Texas wild rice now only grows in the middle of the river, perhaps due to the proliferation of wild taro along the edge of the river (Atkins and Williamson 2008, Staton 1992). If not managed effectively, *Colocasia esculenta* has a the potential to spread into additional sites now occupied by native vegetation (Akridge and Fonteyn 1981, Atkins and Williamson 2008, Nesom 2009).

Sargassum (*Sargassum fluitans* and *Sargassum natans*)

In 2011, *Sargassum fluitans* was added to the Global Invasive Species Database (ISSG 2011). *Sargassum fluitans* 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).

When Sargassam lands along the Texas shoreline, it creates complicated problems for residents of the area. According to Keith Arnold, the CEO of the Corpus Christi Convention Center and Visitors Bureau, tourists expect "prisitine beaches" and view seaweed mats as a "vision of poor beach maintenance." He argues that there is an inverse relationship between seaweed amounts and visitor numbers (Arnold 2008). In local economies that are basically dependent upon tourism dollars, maintaining or increasing tourist numbers is essential (Arnold 2008, Pettis 2008). Additionally, Sargassum maintenance prevents the accumulation of refuse that frequently mixes in with the seaweed and tar creating a "trashy" appearance. The enormous size of these mounds can also deter the nesting of Kemp's ridley sea turtles (*Lepidochelys kempii*) (Smith-Engle 2008). Also, Texas coastal communities are running out of space for maintenance dunes. A wide section of dry beach is needed for dune growth and in some locations the beach width is extremely narrow (Watson 2008).

Growth and Propagation Methods

In addition to conducting a literature review on the propagation methods and local ecology of wild taro and brown algae, the researcher also obtained information from various experts in the fields of biology and botany regarding the propagation methods of *Colocasia esculenta,* specifically.

Wild Taro (*Colocasia esculenta*)

Vegetative Propagation

Reproduction of wild taro in the U.S. usually occurs asexually by vegetative propagation and rarely by sexual reproduction. Scientific literature frequently refers to the large, starchy, bulbous, root-like structures as corms (Atkins and Williamson 2008, Christman 2008, Langeland and Burks 1988, TIPPC 2008), yet additional literature describes the plant as a starch-filled rhizome that grows horizontally underground with stolons (Akridge and Fonteyn 1981, Cook, et al. 1974). The Invasive Plant Atlas of the United States, a collaborative project between the National Park Service and the University of Georgia Center for Invasive Species and Ecosystem Health, describes *Colocasia esculenta* as a plant that "originates from a large corm... that spreads vegetatively through rhizomes" (The University of Georgia - Center for Invasive Species and Ecosystem Health 2012, p. 1).

This statement matches the opinion of local field experts. Dr. David Lemke notes, "the large bulbous structures are best called corms, but (at least) some of the corms give rise to rhizomes that allow the plant to spread laterally" (D. Lemke, personal communication, May 2, 2012). Jackie Poole identifies the starchy structures as corms with rhizomes that "grow below ground,...are elongate and spread horizontally" (J. Poole, personal communication, May 9, 2012). Poole also highlights a semantics issue in the literature when identifying *Colocasia esculenta* as having rhizomes and stolons. "Most people don't distinguish between the two, but rhizomes are usually below ground while stolons are on or just below the ground. (Both) are elongate and spread horizontally" (J. Poole, personal communication, May 9, 2012).

Corms and rhizomes are both underground storage organs, yet differences lie in the structure and lifespan. *The Concise Oxford Dictionary of Botany* defines corms as "formed from a swollen stem base often bearing adventitious roots and scale leaves (that is) often renewed annually" (Allaby 1992, p. 105). Rhizomes are defined as "horizontally creeping underground stem(s) which bears roots and leaves and usually persists from season to season" (Allaby 1992, p. 354). Based on these definitions, communication with experts and the researcher's examination of the physical structure of the organ, root structures were referred to as rhizomes during the course of this project.

Spread of the plant may occur when the bulbous structures divide underground during winter or early spring (MacDonald et al. 2008). Wild taro can also spread via accidental dispersion of rhizomes through flood events or human disturbance. The subsequent reburial of bud-laden rhizomes downstream can lead to the formation of new plants (Akridge and Fonteyn 1981, Atkins and Williamson 2008). According to Atkins and Williamson (2008), "only a portion of the (rhizome) crown and petiole is needed to establish a new plant" (p. 159). Manner and Taylor (2011) noted that wild taro is commercially produced in Hawaii "from mature (rhizomes) and consist of the top 1 cm of the (rhizome) and about 20 to 50 cm of the petiole... (and) are also made from suckers in a similar fashion" (p. 10).

Sexual Reproduction

Inflorescences enveloped by a yellowish bract form occasionally on a fleshy stalk reaching a height lower than the leaves (Cook et al. 1974). Tiny, densely packed flowers form on the apex of the stalk, "with female flowers below and male flowers above" (Langeland and Burks 1988). Sterile flowers form between and above the male flowers. The spadix is shorter than the spathe (Cook et al. 1974). Fruit is not often seen and seed production is uncommon (MacDonald et al. 2008). Clusters of small berries form after flowering. Two or 3 seeds form within each berry, yet this rarely occurs (Galveston Bay Estuary Program 2010, Langeland and Burks 1988). The seeds that are produced have low viability and are difficult to germinate (Langeland and Burks 1988, MacDonald et al. 2008, University of Georgia - Center for Invasive Species and Ecosystem Health 2012). Being that wild taro rarely seeds, and produces low viablilty seeds when production occurs, "it is doubtful that seed dispersal is an important factor in the establishment of (new) stands" (Akridge and Fonteyn 1981).

Sargassum (*Sargassum fluitans* and *Sargassum natans*)

Vegetative Propagation

Free-floating species of Sargassum, which include *Sargassum fluitans* and *Sargassum natans*, reproduce asexually by fragmentation (Awasthi 2005, Rogers 2011). Fragmentation occurs when parts of the thallus grow old, decay and separate from the younger parts. Fragmentation can also occur via physical injury to any part of the plant. Younger parts of the plant then break off and mature into fully-formed organisms. Neither asexual reproduction via spores nor sexual reproduction via seeds are methods of multiplication employed by *Sargassum fluitans* and *Sargassum natans* (Rogers 2011, Coston-Clements et al. 1991, Weis 1968).

Viability

Sargassum fluitans and *Sargassum natans*, like the majority of their pelagic algae counterparts, require a variety of physical and chemical properties in their environment to survive. These include: the circulation of water for continual exposure to nutrients and waste removal, a growth medium consisting of a dynamic system of water, organic components, dissolved gases and dissolved salts and access to light (Fritsch 1965, Round 1981). Additionally, Sargassum requires warmer oceans and sea temperatures to thrive (Abbott and Dawson 1978, Fritsch 1965). If elements of this complex system are missing (e.g. removed from ocean, salinity extracted, etc.), *Sargassum fluitans* and *Sargassum natans* are rendered inviable. Additionally, Sargassum decreases in size dramatically upon landing on the shoreline. Within a 5 day period after landing on the shore, the seaweed decreases approximately 3 times in mass, becomes brittle and changes from a light yellow to dark brown color (Figure 1).

FIGURE 1. Sargassum (*Sargassum fluitans* and *Sargassum natans*) observed at various stages of decomposition after reaching the Corpus Christi shoreline varying in appearance and structure from day 5 (left), day 3 (middle) and day 1 (right) (photo by researcher).

Viability Test Results

The researcher conducted growth tests and oven kill tests to determine additional propagation techniques and temperatures required to kill propagules of *Colocasia esculenta*, specifically. Sargassum samples were not tested because they are rendered inviable when removed from the oceanic environment (Abbott and Dawson 1978, Fritsch 1965, Round 1981).

Wild Taro Growth Test Results

One hundred and eighty propagules were subjected to growth tests. After the 14 day period, all propagules identified as "turgid" and ranked by size displayed continued growth. No turgid wild taro plant rotted or died, regardless of the size of propagule. Alternatively, none of the propagules identified as "dried" showed any sign of growth after the 14 day period. None of these samples displayed root or shoot formation. Additionally, each dried wild taro sample displayed signs of decomposition, lost turgidity and/or was malodorous. Therefore, results showed that any turgid propagule approximately 1 to 50 cm in length will grow. However, propagules dried for 60 days are no longer viable.

<u>Wild Taro Oven Kill Test Results</u>

A total of 270 wild taro propagules were subjected to oven kill tests to mimic conditions in active composting piles and to identify the average temperature propagules were rendered inviable. Dried propagules were not subjected to oven kill tests because they were identified as inviable after the growth tests.

Analysis of the viability tests completed on wild taro (*Colocasia esculenta*) samples showed that propagules decomposed during the oven kill tests or the subsequent post-oven kill growth tests. The majority of propagules lost turgidity, became dark brown in color, grew malodorous and failed to show signs of growth via root formation. One outlier propagule existed: one whole rhizome with 20 to 50 cm of its petiole attached and exposed to an average temperature within the 53 C to 61 C range remained firm after the post-oven kill growth test, yet showed no additional signs of viability. Following the growth test, the sample was dissected to reveal a change in coloration from yellow to dark brown and red. Although this sample remained turgid and did not become malodorous, the change in coloration and the lack of viability signs resulted in the researcher identifying the propagule as inviable. Subsequently, oven tests rendered all propagules inviable when exposed to temperatures of 45 to 52 C for a minimum of 3 days (Table 4). Similar results have been identified in related studies (Meier 2011, Montoya et al. 2013).

TABLE 4. Wild taro (*Colocasia esculenta*) oven kill and post-oven kill growth tests results conducted on whole rhizomes with 20 to 50 cm of the petiole attached, the top 1 cm of the rhizome attached to the petiole or the top 1 cm of the rhizome without petiole attached in the study of using large-scale composting as an alternative means to manage invasive species.

Group	Propagule No.	Post-Oven Kill Growth Test	% Viability
Whole Rhizomes with 20 to 50 cm of the Petiole Attached			
45 C - 52 C	30	14/30	0%
53 C - 61 C	30	9/30	0%
62 C - 71 C	30	1/30	0%
Sub Total	90	24/90	0%
Top 1 cm of Rhizome Portion Attached to the Petiole			
45 C - 52 C	30	7/30	0%
53 C - 61 C	30	7/30	0%
62 C - 71 C	30	0/30	0%
Sub Total	90	14/90	0%
Top 1 cm of the Rhizome Portion without Petiole Attached			
45 C - 52 C	30	0/30	0%
53 C - 61 C	30	3/30	0%
62 C - 71 C	30	4/30	0%
Sub Total	90	7/90	0%
Total	270	45/270	0%

Compost Management Results

The initial planned recipe used for all piles was 25% invasive species, 25% food waste and 50% wood chips (Meier 2011, Montoya et al. 2013). Ratios of feedstocks for piles needed to be adjusted after natural shrinkage of wild taro occured following the drying process. Sargassam also dried down after its removal from the saline, aquatic environment (City of Corpus Christi 2011). A total of 12 piles were created. Each compost pile was monitored to ensure ideal conditions were met for the composting process: using a proper ratio of materials, maintaining a sufficient water supply through weekly thorough irrigation of the piles, proper aeration via weekly pile rotation and allowing for temperatures to reach approximately 62 C to 71 C for a minimum of 3 days. Each pile included approximately 12 cubic yards of feedstocks, totaling approximately 144 cubic yards of feedstocks (Table 5). Following the reduction of materials during the composting process, approximately 50 cubic yards of cured compost were created.

TABLE 5. Four compost pile recipe percentages and total cubic yards using 2 invasive species subjected to different treatments including dried wild taro (*Colocasia esculenta*), turgid wild taro (*Colocasia esculenta*), treated brown algae (*Sargassum* spp.) and non-treated brown algae (*Sargassum* spp.) following biomass shrinkage in the study of using large-scale composting as an alternative means to manage invasive species.

Colocasia esculenta	Invasive Species	Food Waste	Wood Chips	Pile No. (Total yd³)
Dried:% of piles	~2%	~42%	~56%	3
Dried: (yd³)	(~0.25)	(~4.33)	(~5.83)	(~10.41)
Turgid:% of piles	~20%	~30%	~50%	3
Turgid: (yd³)	(~2.5)	(~4.33)	(~6.33)	(~13.16)
Sargassum spp.	Invasive Species	Food Waste	Wood Chips	Pile No. (Total yd³)
Treated:% of piles	~2%	~44%	~54%	3
Treated: (yd³)	(~0.17)	(~4.67)	(~6.67)	(~11.51)
Non-treated:% of piles	~2%	~45%	~53%	3
Non-Treated: (yd³)	(~0.33)	(~5.75)	(~5.67)	(~11.75)
			Total Pile No.	**12**

Approximately 18 cubic yards of wild taro were harvested for the compost management component of this study. Nine cubic yards were dried on a concrete block. Following the drying process, the 9 cubic yards shrunk to approximately 1 cubic yard. From this amount, dried propagules were chosen randomly for growth tests. The remaining biomass was then distributed evenly into the 3 piles created with dried wild taro propagules as a feedstock.

A total of approximately 18 cubic yards of "fresh" seaweed (Sargassum that arrived on the shoreline during the previous 24 hours) was harvested from the City of Corpus Christi for this study. Within 5 days, the biomass had shrunk to approximately 2 cubic yards due to natural processes after it is removed from its saline, aquatic environment. Approximately 50% of this biomass (approximately 1 cubic yard) was distributed evenly as a feedstock into 3 compost piles. The remaining 50% of the harvested brown algae underwent a treatment of being manually washed with tap water to remove as much tar, salt and sand as possible. All trash and tar balls of a size 2 cm or larger were manually removed from the biomass. The treatment of these piles resulted in additional biomass shrinkage. The amount of Sargassum to be used in each of the treated piles dropped from 1 cubic yard to 0.5 cubic yard after the washing treatment. This 0.5 cubic yard amount was then distributed evenly among 3 compost piles utilizing treated Sargassam as a feedstock. Subsequently, pile ratios were altered to maintain proper C:N ratios and achieve temperatures required for adequate decomposition (Table 5) (Rynk 1992).

During the active stage of compost pile formation, 2 piles exhibited abnormally acidic pH readings with average lows of 4.5 and 3.8, respectfully. One pile included non-treated seaweed and the other included turgid taro as a compost feedstock. By the beginning of the curing phase, pH levels reached ideal ranges without adjustments to feedstocks. The low pH was potentially due to the varying types of food waste incorporated into the research piles. Large amounts of coffee grounds were intially placed into these 2 piles, specifically. After heavy thunderstorms, the researcher also noticed increased acidity throughout all piles being tested. Again, these fluctuations normalized without assistance from the researcher during the active stage of the composting process.

Compost Quality and Testing Results

Laboratory Screening Test Results

Representative samples of the final compost product from each pile using wild taro as a feedstock were tested independently by the researcher to determine if *Colocasia esculenta* propagules were rendered inviable. Material from all 6 piles with *Colocasia esculenta* subjected to different treatments (3 turgid piles and 3 dried piles, separately) were combined to create composite samples, totaling 2 final composite samples of 170.3 L of compost each (Meier 2011, Montoya et al. 2013). Each composite sample was manually sifted through a 1.27 cm screener to identify remaining propagules.

A total of approximately 25 mL of wild taro remains were identified in the 170.3 L composite sample from piles using turgid wild taro propagules as a feedstock (Figure 2.1 and 2.2). None were identified as viable due to their brown or black color, lack of turgidity and fragmentation**.** Individual taro remains in the material screened out of the compost piles which incorporated turgid wild taro propagules ranged from approximately 1.5 cm to 4 cm in length and were also inviable. Therefore, if temperatures in compost piles reach 45 to 62 C for a minimum of 3 days, then wild taro propagules can safely be composted. Remaining propagule fragments can be screened out with additional large carbon-based fragements (e.g. non-decomposed wood chips) and can then be reincorporated into future composting cycles. Additionally, the composite sample created from piles using dried taro as a feedstock produced no identifiable plant remains. Therefore, large-scale composting renders all wild taro propagules inviable and is a suitable tool in the management of this invasive plant.

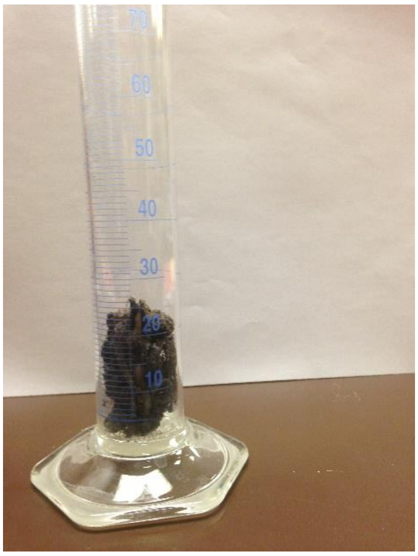

FIGURE 2.1. Total wild taro (*Colocasia esculenta*) biomass (25 mL) rendered inviable following the composting process using turgid wild taro as a feedstock (photo by researcher).

FIGURE 2.2. Total wild taro (*Colocasia esculenta*) biomass (25 mL) rendered inviable following the composting process using turgid wild taro as a feedstock (photo by author).

<u>Quality Test Results</u>

Composite samples of the final compost product from each of the 12 piles underwent compost quality tests conducted by staff members at Pennsylvania State University. A total of 4 composite samples (1 from each compost recipe) were tested. These compost quality tests were used determine if large-scale composting methods for *Colocasia esculenta* and *Sargassum* spp. resulted in compost with quality levels considered safe and marketable by the composting industry.

The pH, soluble salt content, total nitrogen, total carbon, C:N ratio, particle size, bioassay and respirometry measurements of all samples were within the ideal and desirable ranges for compost sold in the horticultural industry (Table 6). Additionally, heavy metal content did not exceed normal ranges nor were weed seeds or propagules present. The lack of propagules present in the compost samples confirmed findings from laboratory tests showing that large-scale composting can be used to manage wild taro.

TABLE 6. Compost quality test results of 4 composite compost samples analysed at Pennsylvania State University using dried wild taro (*Colocasia esculenta*), turgid wild taro (*Colocasia esculenta*), treated brown algae (*Sargassum* spp.) and non-treated brown algae (*Sargassum* spp.) as feedstocks in the study of using large-scale composting as an alternative means to manage invasive species.

Variable (Units)	Range (As Is Basis)	Mean (As Is Basis)	Range (Dry Weight Basis)	Mean (Dry Weight Basis)	Normal Range (US Composting Council 2002)
pH	8.1-8.4	8.3	n/a	n/a	5.0-8.5
Soluble Salts (mmhos/cm)	1.10-1.59	1.33	n/a	n/a	1-10
Solids (%)	74.7-57.0	63.3	n/a	n/a	50-60
Moisture (%)	25.3-43.0	36.7	n/a	n/a	40-50
Organic Matter (%)	17.8-23.0	21	30.8-36.3	33.3	30-70 (Dry weight)
Total Nitrogen (%)	0.7-1.1	0.9	1.3-1.7	1.4	0.5-2.5 (Dry weight)
Carbon (%)	9.8-13.6	11.9	17.3-21.3	18.8	< 54 (Dry weight)
Carbon to Nitrogen (C:N) Ratio	12.40-13.50	13.18	12.40-13.50	13.18	< 20 (Dry weight)
Phosphorus (%)	0.31-0.43	0.37	0.48-0.68	0.58	n/a
Potassium (%)	0.39-0.46	0.43	0.60-0.72	0.68	n/a
Bioassay: Emergence (% of control)	100	100	n/a	n/a	> 90 (Very mature)
Bioassay: Seedling Vigor (%)	100	100	n/a	n/a	> 95 (Very mature)
Respirometry (mg CO^2-C/g organic matter/day)	1.8-2.3	2.1	n/a	n/a	< 2 (Very stable) 2-8 (Stable)

According to the US 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 (US Composting Council 2002). The compost ratios included acidic and alkaline feedstocks: acidic feedstocks included food waste and wood chips while seaweed is identified as slightly alkaline (Cooperband 2002, Darlington 2007, Dougherty 1999, Eyras et al. 1998, Maze et al. 1993). All identifiable paper waste, a neutral pH product, was removed (Cooperband 2002, Dougherty 1999, US Composting Council 2001). Piles that are allowed to cure for 3 to 4 months tend to have lower pH measurements (Dougherty 2002). Therefore, curing piles for longer than 1 month would allow the compost more time to become less alkaline.

Soluble salt content in each of the piles ranged from 1.10 to 1.59 mmhos/cm and was well within the safe soluble salt content range of 1.0 to 10.0 mmhos/cm (US Composting Council 2002). Regardless of the feedstocks used, salt content was not affected in the final product. The 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 brown algae 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 normal range of total nitrogen content identified by the US Composting Council (2002) was between 0.5 and 2.5% (dry weight basis). The total nitrogen content in the representative samples ranged from 0.7 to 1.1%. The ideal total carbon identified by the US Composting Council (2002) was less than 54%. The range of total carbon in the samples varied from 17.3 to 21.3%. C:N ratios of 20 or below allow organic nitrogen to break down to an inorganic, plant-available form of nitrogen (US Composting Council 2002). The C:N ratios of the samples were between 12.40 to 13.50. Therefore, the compost produced in this study would increase plant nutrient availability when applied to soil.

Bioassay tests measured maturity of the compost based on emergence and seedling vigor. Compost is rated as "very mature" if emergence readings are greater than 90% and seedling vigor readings are greater than 95% (US 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 US Composting Council (2002) rates compost with respirometry test results with readings of 0.1 to 2.0 as "very stable" while readings from 2.1 to 8.0 are identified as "stable." The average respirometery reading for the compost samples was 2.1. Individual samples were identified within the range of 1.8 to 2.3. Subsequently, all compost samples were considered to be stable products to for use in the industry.

Although some of the samples did not have the ideal levels of percent moisture and percent solids, the compost produced was still considered a quality product for the horticultural markets. The ideal percent solids amount was 50 to 60%, while the ideal percent moisture content was 50 to 40% (US Composting Council 2002). The samples from the 2 representative piles that had abnormally high solids content were piles that inadvertently contained materials from the compost site foundation. Operations at the Texas State University Bobcat Blend composting site should include improved training of skid loader operators on how to handle machinery to prevent solids from entering the product.

CHAPTER V

DISCUSSION

Purpose

This project examined large-scale compost management of 3 aquatic species: *Colocasia esculenta* (wild taro), *Sargassum fluitans* and *Sargassum natans* (brown algae, collectively). Each species posed threats to local ecosystems in Texas. This study investigated whether compost management systems offered an effective alternative system of management by rendering the seeds and additional propagules of these species unviable, while creating a marketable byproduct for use in agriculture, horticulture and related markets.

Objectives

The objectives of this study included (1) identifying invasive or problematic species with widespread distribution in Texas that posed a threat to local ecosystems, (2) understanding how each species grew, propagated and functioned in local plant and wildlife communities, (3) evaluating if the natural compost process effectively killed seeds and other propagules as well as eliminated potentially high levels of salinity and (4) determining if large-scale compost management of these organisms offered an effective alternative to current management systems while creating safe, marketable products for the agricultural and horticultural consumer.

Identification of Invasive Species

The researcher conducted an extensive literature review and spoke with experts in the field to determine species that pose threats to local aquatic ecosystems in Texas: *Colocasia esculenta* (wild taro), *Sargassum fluitans* and *Sargassum natans* (brown algae, collectively). Wild taro [*Colocasia esculenta* (L.) Schott] is an exotic species invasive to the San Marcos River ecosystem, negatively impacting endangered species in the river's headwaters. Thriving in freshwater swamps, streambanks and riparian areas, the species is identified as invasive throughout the southeastern United States as well as Puerto Rico, Jamaica and India. *Sargassum fluitans* was added to the Global Invasive Species Database in 2011. Massive drifts of brown algae, known collectively and colloquially as Sargassum (*Sargassum fluitans* and *Sargassum natans*), float onto the United States Gulf and Atlantic coasts and European shorelines with regularity throughout the spring and summer months, creating complicated management problems for residents.

Growth and Propagation Methods

Reproduction of wild taro in the U.S. usually occurs asexually by vegetative propagation and rarely by sexual reproduction. Wild taro rarely seeds. When seeds are created, they have low viability and are difficult to germinate (Akridge and Fonteyn 1981, Langeland and Burks 1988, MacDonald et al. 2008, University of Georgia - Center for Invasive Species and Ecosystem Health, 2012). Wild taro chiefly spreads via division of rhizomes underground, accidental dispersion of rhizomes through flood events or human disturbance or the subsequent reburial of bud-laden rhizomes downstream (Akridge and Fonteyn 1981, Atkins and Williamson 2008, MacDonald et al. 2008). Manner and Taylor (2011) noted that wild taro is commercially produced in Hawaii "from mature (rhizomes) and consist of the top 1 cm of the (rhizome) and about 20 to 50 cm of the petiole " (p. 10). *Sargassum fluitans* and *Sargassum natans* reproduce asexually by fragmentation only and are rendered inviable when removed from the oceanic environment (Awasthi 2005, Fritsch 1965, Rogers 2011, Round 1981).

Viability Test Results

The researcher conducted growth tests, oven kill tests and post-oven kill growth tests to determine additional propagation techniques and temperatures required to kill propagules of *Colocasia esculenta*, specifically. Sargassum samples were not tested because they are rendered inviable when removed from the oceanic environment (Abbott and Dawson 1978, Fritsch 1965, Round 1981).

Results of the growth tests showed that any turgid propagule approximately 1 to 50 cm in length will grow. However, propagules dried for 60 days are no longer viable. Analysis of the oven kill tests and post-oven kill growth tests completed on wild taro samples showed that exposure of the propagules to temperatures of 45 to 52 C for a minimum of 3 days rendered all propagules inviable. Therefore, wild taro propagules used in large-scale composting will be rendered inviable and is an safe and effective compost feedstock.

Compost Management Results

A total of 12 piles approximately 1.8 m in height and 3 m in length were created. Each pile contained 12 cubic yards of feedstocks including wild taro (*Colocasia esculenta*) and brown algae (*Sargassum fluitans* and *Sargassum natans*) separately, food waste from cafeterias at Texas State University and wood chips produced and donated by Bartlett Tree Company. A total of approximately 144 cubic yards of feedstocks were used. Approximately 18 cubic yards of each species were harvested for the compost management component of this study. The initially planned recipe used for all piles was 25% invasive species, 25% food waste and 50% wood chips (Meier 2011, Montoya et al. 2013). Ratios for piles were altered due to the shrinkage of wild taro following the drying process and reduction of Sargassam due to natural processes after the seaweed is removed from its saline, aquatic environment (City of Corpus Christi 2011). Pile ratios were altered to maintain proper C:N ratios and achieve temperatures required for adequate decomposition (Rynk 1992).

Following the decomposition of materials during the composting process, approximately 50 cubic yards of cured compost were created.

Compost Quality and Testing Results

Laboratory testing was conducted by the researcher to evaluate whether high temperatures reached via composting rendered all wild taro (*Colocasia esculenta*) propagules inviable. Quality testing was conducted by the US Composting Council's Seal of Testing Approval (STA) Program at Pennsylania State University to evaluate whether treatment methods on piles rendered the final compost product safe and valuable.

Results of laboratory screening tests showed no identifiable plant fragments in the compost created using dried taro as a feedstock. Although approximately 25 mL of wild taro remains were identified in the composite sample from piles using turgid wild taro propagules as a feedstock, none were identified as viable. Therefore, propagule remains can safely remain in the final compost product or be screened out with additional carbon-based fragments (e.g. non-decomposed wood chips) to be used as feedstock for future composting cycles. Due to the small size and fine consistency of the remaining biomass, the propagules are expected to decompose after 1 additional compost cycle. Therefore, large-scale composting renders all wild taro propagules inviable and is a safe and effective tool in the management of this invasive plant, as opposed to the use of herbicides or disposal of the biomass in a landfill.

Quality tests conducted on the representative samples identified the final compost products to have quality levels considered safe and desirable by the composting and horticultural industries. Regardless of the feedstocks used, no viable propagules were found nor did salt content affect in the quality of the final product. The lack of propagules present in the compost samples confirmed findings from laboratory tests showing that large-scale composting can be used to safely manage wild taro and be utilized to create a quality horticultural product. Also, the final compost products created did not include salinity levels potentially harmful to plants The products can be used to promote plant health. Therefore, when the amount of brown algae that arrives on the shoreline exceeds the amount that can be integrated into management dunes, the biomass could be used as a feedstock in potentially greater quantities in the compost ratio to create final compost products that are valuable to the horticultural industry.

The pH of initial feedstocks is not a major characteristic emphasized when considering feedstocks to use in compost creation. Literature heavily emphasizes researching bulk density, percent moisture, percent solids and C:N ratios when determining initial feedstock ratios (Cooperband 2002, Darlington 2007, Dougherty 1999, Rynk 1992). The pH measurements of initial feedstocks should be more heavily considered in pile formation. According to the US Composting Council (2002), the ideal pH range for compost is between 5.0 and 8.5. Although the intial feedstock ratios included high proportions of food waste and tree biomass, feedstocks that are typically identified as acidic, the measurements of the samples ranged from 8.1 to 8.4 (Cooperband 2002, Dougherty 1999). While these measurements are alkaline, they were within the acceptable pH ranges for finished compost (US Composting Council 2002). Compost products created with initial ratios using more quantities of acidic feedstocks (e.g. food waste, leaf matter or pine needles) would potentially result in products with more neutrialized pH measurements (Cooperband 2002, Dougherty 1999). However, piles that are allowed to cure for 3 to 4 months tend to have lower pH measurements (Dougherty 2002).

Although some of the samples did not have the ideal levels of percent moisture and percent solids, the compost produced was still considered a quality product for the horticultural markets. The samples from the 2 representative piles that had abnormally high solids content were gathered from the compost piles that inadvertently contained materials from the compost site foundation. Operations at the Texas State University Bobcat Blend composting site should include improved training of skid loader operators on how to handle machinery to prevent solids from entering the product.

Management Implications

Wild taro [*Colocasia esculenta* (L.) Schott] is an exotic species identified as invasive throughout the southeastern United States as well as Puerto Rico, Jamaica and India. Current management systems include the manual removal, the use of herbicides and hauling the biomass to a landfill. Massive drifts of brown algae, known collectively and colloquially as Sargassum (*Sargassum fluitans* and *Sargassum natans*), float onto the Atlantic shorelines with regularity, creating complicated management problems for residents and the economic viability of coastal communities. Current management techniques in Texas include dumping the biomass back into the ocean or creating management dunes. Texas coastal communities are running out of space for the creation of the management dunes due to rising sea levels, erosion and the increase in dune size over time. Dune size may also impede tourist enjoyment of the space, potentially impacting the economic viability of some communities. Additionally, *Sargassum fluitans* was added to the Global Invasive Species Database in 2011.

The intent of this study was determine if large-scale composting is an effective technique for the management of wild taro and brown algae. This study used approximately 18 cubic yards of *Sargassum* spp. and 18 cubic yards of *Colocasia* *esculenta* as feedstocks mixed with food waste from Texas State University and wood chips from the region. A total of approximately 144 cubic yards of feedstocks were used. Following the decomposition of materials during the composting process, approximately 50 cubic yards of cured compost were created. This product, created from materials otherwise considered problematic, was valued at $1,800 on the local market (G. Frank, personal communication, October 15, 2013). Oven kill tests determined that wild taro propagules exposed to temperatures between 45 C to 52 C for a mimium of 3 days were rendered inviable. These temperatures were achieved during the active phase of the composting process. Testing conducted by the researcher and Pennsylvania State University Agricultural Analytical Services Laboratory determined that the final compost products created were safe, valuable, of equal or higher quality to current compost standards and, subsequently, desirable to the horticultural industry. Therefore, this study determined that the horticultural industry can utilize wild taro and brown algae as feedstocks to create a desirable compost product while helping to manage invasive species, rather than managing the biomass with traditional disposal methods. Additionally, when the amount of brown algae that arrives on the shoreline exceeds the amount that can be integrated into management dunes, the biomass could be used as a feedstock in potentially greater quantities in the compost ratio to create final compost products that are valuable to the horticultural industry.

Recommendations for Future Studies

Future studies should (1) include a cost-benefit analysis of the environmental and monetary impacts of the removal of wild taro (*Colocasia esculenta*) by manual removal / composting as opposed to the use of chemical control (e.g. herbicides), (2) focus on the use of Sargassum that has naturally decomposed for a minimum of 5 days as a potential compost feedstock, (3) attempt to identify the maximum amount and proper ratios of non-treated, 5 day-old Sargassum that can be used as a feedstock for compost creation to result in safe and valuable compost products, (4) investigate the uses, applications and marketability of compost products created from wild taro or brown algae, (5) investigate compost feedstock ratios resulting in compost with acidic to neutral pH measurements to assist local users of the product in balancing the pH of the chiefly alkaline soils in Central Texas, (6) analyze all Pennsylvania State University quality test results accrued by the Department of Agriculture at Texas State University in related projects and created by Central Texas compost producers and (7) conduct more intensive analysis on the microbial and chemical properties of compost created using varying ratios.

APPENDIX

PENNSTATE

(814) 863-0841 Fax (814) 863-4540
Agricultural Analytical Services Laboratory
The Pennsylvania State University
University Park PA 16802

Analysis Report For:	Copy To:
Jen Sembura 851 Peach Street Lockhart TX 78644	

LAB ID:	SAMPLE ID:	REPORT DATE:	SAMPLE TYPE:	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06634	#A-C : taro(turgid)	9/16/2013	Finished Compost		Windrow	

COMPOST ANALYSIS REPORT

Compost Test 3A

Analyte	Results (As is basis)	Results (Dry weight basis)
pH	8.4	——
Soluble Salts (1:5 w:w)	1.10 mmhos/cm	——
Solids	57.0 %	——
Moisture	43.0 %	
Organic Matter	17.8 %	31.2 %
Total Nitrogen (N)	0.7 %	1.3 %
Organic Nitrogen[1]	0.7 %	1.3 %
Ammonium N (NH_4-N)	< 2.8 mg/kg *or* < 0.0003 **%**	< 4.9 mg/kg *or* < 0.0005 **%**
Carbon (C)	9.8 %	17.3 %
Carbon:Nitrogen (C:N) Ratio	13.40	13.40
Phosphorus (as P_2O_5)[2]	0.31 %	0.55 %
Potassium (as K_2O)[2]	0.39 %	0.68 %
Calcium (Ca)	3.56 %	6.25 %
Magnesium (Mg)	0.24 %	0.42 %
Particle size (< 9.5 mm)	100.00 %	——

[1]See comments on back of report .
[2]To convert phosphorus (as P_2O_5) into elemental phosphorus (P), divide by 2.29. To convert potassium (as K_2O) into elemental potassium (K), divide by 1.20.

INTERPRETATION

pH

pH is a measure of active acidity in the feedstock or compost. The pH scale is 0 (acidic) to 14 (basic) with 7 being neutral. Most finished composts will have pH values in the range of 5.0 to 8.5. Ideal pH depends on compost use. A lower pH is preferred for certain ornamental plants while a neutral pH is suitable for most other applications. pH is not a measure of the total acidity or alkalinity and cannot be used to predict the effect of compost on soil pH.

Soluble Salts

Soluble salts are determined by measuring electrical conductivity (EC) in a 1:5 (compost:water, weight ratio) slurry. EC is related to the total soluble salts dissolved in the slurry and is measured in units of millimhos/cm (mmhos/cm). Compost soluble salt levels typically range from 1 to 10 mmhos/cm. High salinity may be toxic to plants. Ideal soluble salt levels will depend on the end use of the compost. Final compost blends with soil or container media/potting mixes should be tested for soluble salts.

% Solids, % Moisutre

The ideal moisture content for composting will depend on the water holding capacity of the materials being composted. In general, high organic matter materials have a higher water holding capacity and a higher ideal moisture content. A typical starting compost mix will have an ideal % solids content of 35-55 % (65-45 % moisture). Finished compost should have a % solids content of 50-60 % (50-40 % moisture).

% Organic Matter

There is no ideal organic matter level for feedstocks or finished compost. Organic matter content will decrease during composting. The organic matter content (dry weight basis) of typical feedstocks and starting mixes will be greater than 60 % while that of finished compost will be in the range of 30-70 %. An organic matter content (dry weight basis) of 50-60 % is desirable for most compost uses.

Nitrogen : Total, Organic, Ammonium, and Nitrate

Total nitrogen (N) includes all forms of nitrogen: organic N, ammonium N (NH_4-N), and nitrate N (NO_3-N). Total N will normally range from less than 1 % to around 5 % (dry weight basis) in most feedstocks and from 0.5 to 2.5 % (dry weight basis) in finished composts. NO_3-N (an optional test) is generally present in only low concentrations in immature composts, although it may increase as the compost matures. NH_4-N levels may be high during initial stages of the composting process, but decrease as maturity increases. Organic N is determined by subtracting the inorganic N forms, NH_4-N and NO_3-N, from total N. However, because NO_3-N levels are generally very low, total nitrogen minus NH_4-N provides a good estimate of organic N in most composts and is the value shown on the front of this report. In stable, finished composts, most of the N should be in the organic form. While NH_4-N and NO_3-N are immediately available to plants, organic N is only slowly available, approximately 10 to 20 % per year. However, mineralization or break-down of organic N into available inorganic forms depends on the C:N ratio (see below) as well as factors such as soil moisture and temperature.

Total Carbon

Total carbon (C) is a direct measurement of all organic and inorganic carbon in the compost sample. Unless the sample has a high pH (> 8.3) or is known to contain carbonates, essentially all carbon will be in the organic form. Compost organic matter typically contains around 54 % organic carbon by weight. The carbon content of individual feedstocks may vary from this ratio.

Carbon: Nitrogen Ratio

This is the ratio of total carbon (C) to total nitrogen (N) in the compost sample provided. C:N ratio may be used as an indicator of compost stability and N availability. Compost C:N ratio typically decreases during composting if the starting C:N ratio is > 25, but may increase if the starting C:N ratio is low (< 15) and N is lost during the composting process. Composts with high C:N ratios (> 30) will likely immobilize or tie-up N if applied to soil, while those with low C:N ratios (< 20) will mineralize or break-down organic N to inorganic (plant-available) N.

Phosphorus, Potassium

Phosphorus (P) and potassium (K) are plant macronutrients. Values reported are for total amounts given in the oxide forms (P_2O_5 and K_2O). These results provide an indication of the nutrient value of the compost sample. However, plant availability of total phosphorus and potassium in compost has not yet been established.

Nitrogen, Phosphorus, Potassium Balance

When compost is applied on the basis of nitrogen (N), most composts will have an excess of phosphorus (P) and potassium (K) relative to crop demand. These mineral elements and salts can accumulate to above optimum levels with repeated application. Growers using compost should regularly soil test to monitor P, K and salt accumulation and should consider using other nutrient sources or nitrogen fixing legumes in their crop rotation especially when P and K levels are above optimum.

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LAB ID:	SAMPLE ID:	REPORT DATE:	SAMPLE TYPE:	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06634	#A-C : taro(turgid)	9/16/2013	Finished Compost		Windrow	

COMPOST ANALYSIS REPORT

EPA 503 Pollutants

Analyte	Results (As is Basis)	Results (Dry Weight Basis)	EPA SW 846 Method
Arsenic (As)	4.2 mg/kg	7.4 mg/kg	3050B + 6010
Cadmium (Cd)	< 0.3 mg/kg	< 0.6 mg/kg	3050B + 6010
Copper (Cu)	12.4 mg/kg	21.7 mg/kg	3050B + 6010
Lead (Pb)	4.3 mg/kg	7.6 mg/kg	3050B + 6010
Mercury (Hg)	0.020 mg/kg	0.036 mg/kg	7473
Molybdenum (Mo)	< 0.9 mg/kg	< 1.7 mg/kg	3050B + 6010
Nickel (Ni)	5.4 mg/kg	9.6 mg/kg	3050B + 6010
Selenium (Se)	< 0.9 mg/kg	< 1.7 mg/kg	3050B + 6010
Zinc (Zn)	37.7 mg/kg	66.1 mg/kg	3050B + 6010

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LAB ID	SAMPLE ID	REPORT DATE	SAMPLE TYPE	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06634	#A-C : taro(turgid)	9/16/2013	Finished Compost		Windrow	

COMPOST BIOASSAY
Seedling Emergence and Relative Growth

TEST PARAMETERS

Test Dates:	09/05/2013 to 09/12/2013
Seed Type:	Cucumber-Marketmore 76 Variety
Media Type: ***(Control)***	STA-Green Smart Soil Potting Mix
Vermiculite:	STA-Green Vermiculite

TEST RESULTS

Emergence: (% of control)	100.00
Seedling Vigor: (%):	100.00

COMMENTS

INTERPRETATION

The bioassay test provides a screen for the presence of phytotoxins in compost based on seedling emergence and seedling vigor relative to a control. It provides an assessment of compost maturity although should not be used as a stand-alone indicator. The U.S. Compost Council Test Methods for the Examination of Composting and Compost provides the following Maturity Indicator Ratings based on this test.

Maturity Indicator Rating[1]

Test Parameter	Very Mature	Mature	Immature
Emergence %	> 90	80-90	< 80
Seedling Vigor %	> 95	85-95	< 85

[1] Test Methods for the Examination of Composting and Composts

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LAB ID	SAMPLE ID	REPORT DATE	SAMPLE TYPE	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06634	#A-C : taro(turgid)	9/16/2013	Finished Compost		Windrow	

RESPIROMETRY
Carbon Dioxide (CO_2) Evolution Rate

TEST RESULTS	
mg CO_2-C/g solids/day:	0.6
mg CO_2-C/g organic matter/day:	1.8

INTERPRETATION

Respirometry (CO_2 Evolution) provides a measurement of the relative microbial activity in a compost and, hence can be used as an estimate of compost stability. The intrepretive index below from the U.S. Compost Council Test Methods for the Examination of Composting and Compost assumes optimal conditions for microbial activity are present including temperature, mositure and nutrients and that toxic components that would inhibit microbial respiration are absent.

Result*	Stability Rating	General Characteristics
< 2	Very Stable	Well cured Compost No continued decomposition No odors No potential for volatile fatty acid phytotoxicity and odor
2-8	Stable	Cured Compost Odor production not likely Limited potential for volatile fatty acid phytotoxicity and odor Minimal impact on soil carbon and nitrogen dynamics
8-15	Moderately unstable, raw compost	Uncured compost Minimal odor production Moderate to high potential for volatile fatty acid phytotoxicity Moderate potential for negative impact on soil carbon and nitrogen dynamics
15-40	Raw compost or raw organic products	Uncured Compost Odor production likely High potential for volatile fatty acid phytotoxicity and odor High potential for negative impact on soil carbon and soil nitrogen dynamics
> 40	Raw feedstocks, unstable material	Raw, extremely unstable material Odor production expected Probably volatile fatty acid phytotoxicity with most materials Negative impact on soil carbon and nitrogen dynamics expected Generally not recommended for use as compost

* Units in mg CO_2-C/g organic matter/day

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LAB ID:	SAMPLE ID:	REPORT DATE:	SAMPLE TYPE:	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06635	#D-F : taro(dry)	9/17/2013	Finished Compost		Windrow	

COMPOST ANALYSIS REPORT

Compost Test 3A

Analyte	Results (As is basis)	Results (Dry weight basis)
pH	8.3	—
Soluble Salts (1:5 w:w)	1.50 mmhos/cm	—
Solids	63.9 %	—
Moisture	36.1 %	
Organic Matter	22.2 %	34.7 %
Total Nitrogen (N)	1.1 %	1.7 %
Organic Nitrogen[1]	1.1 %	1.7 %
Ammonium N (NH_4-N)	< 3.2 mg/kg *or* < 0.0003 **%**	< 5.0 mg/kg *or* < 0.0005 **%**
Carbon (C)	13.6 %	21.3 %
Carbon:Nitrogen (C:N) Ratio	12.40	12.40
Phosphorus (as P_2O_5)[2]	0.43 %	0.68 %
Potassium (as K_2O)[2]	0.46 %	0.72 %
Calcium (Ca)	4.03 %	6.30 %
Magnesium (Mg)	0.25 %	0.39 %
Particle size (< 9.5 mm)	100.00 %	—

[1]See comments on back of report .

[2]To convert phosphorus (as P_2O_5) into elemental phosphorus (P), divide by 2.29. To convert potassium (as K_2O) into elemental potassium (K), divide by 1.20.

INTERPRETATION

pH
pH is a measure of active acidity in the feedstock or compost. The pH scale is 0 (acidic) to 14 (basic) with 7 being neutral. Most finished composts will have pH values in the range of 5.0 to 8.5. Ideal pH depends on compost use. A lower pH is preferred for certain ornamental plants while a neutral pH is suitable for most other applications. pH is not a measure of the total acidity or alkalinity and cannot be used to predict the effect of compost on soil pH.

Soluble Salts
Soluble salts are determined by measuring electrical conductivity (EC) in a 1:5 (compost:water, weight ratio) slurry. EC is related to the total soluble salts dissolved in the slurry and is measured in units of millimhos/cm (mmhos/cm). Compost soluble salt levels typically range from 1 to 10 mmhos/cm. High salinity may be toxic to plants. Ideal soluble salt levels will depend on the end use of the compost. Final compost blends with soil or container media/potting mixes should be tested for soluble salts.

% Solids, % Moisutre
The ideal moisture content for composting will depend on the water holding capacity of the materials being composted. In general, high organic matter materials have a higher water holding capacity and a higher ideal moisture content. A typical starting compost mix will have an ideal % solids content of 35-55 % (65-45 % moisture). Finished compost should have a % solids content of 50-60 % (50-40 % moisture).

% Organic Matter
There is no ideal organic matter level for feedstocks or finished compost. Organic matter content will decrease during composting. The organic matter content (dry weight basis) of typical feedstocks and starting mixes will be greater than 60 % while that of finished compost will be in the range of 30-70 %. An organic matter content (dry weight basis) of 50-60 % is desirable for most compost uses.

Nitrogen : Total, Organic, Ammonium, and Nitrate
Total nitrogen (N) includes all forms of nitrogen: organic N, ammonium N (NH_4-N), and nitrate N (NO_3-N). Total N will normally range from less than 1 % to around 5 % (dry weight basis) in most feedstocks and from 0.5 to 2.5 % (dry weight basis) in finished composts. NO_3-N (an optional test) is generally present in only low concentrations in immature composts, although it may increase as the compost matures. NH_4-N levels may be high during initial stages of the composting process, but decrease as maturity increases. Organic N is determined by subtracting the inorganic N forms, NH_4-N and NO_3-N, from total N. However, because NO_3-N levels are generally very low, total nitrogen minus NH_4-N provides a good estimate of organic N in most composts and is the value shown on the front of this report. In stable, finished composts, most of the N should be in the organic form. While NH_4-N and NO_3-N are immediately available to plants, organic N is only slowly available, approximately 10 to 20 % per year. However, mineralization or break-down of organic N into available inorganic forms depends on the C: N ratio (see below) as well as factors such as soil moisture and temperature.

Total Carbon
Total carbon (C) is a direct measurement of all organic and inorganic carbon in the compost sample. Unless the sample has a high pH (> 8.3) or is known to contain carbonates, essentially all carbon will be in the organic form. Compost organic matter typically contains around 54 % organic carbon by weight. The carbon content of individual feedstocks may vary from this ratio.

Carbon: Nitrogen Ratio
This is the ratio of total carbon (C) to total nitrogen (N) in the compost sample provided. C:N ratio may be used as an indicator of compost stability and N availability. Compost C:N ratio typically decreases during composting if the starting C:N ratio is > 25, but may increase if the starting C:N ratio is low (< 15) and N is lost during the composting process. Composts with high C:N ratios (> 30) will likely immobilize or tie-up N if applied to soil, while those with low C:N ratios (< 20) will mineralize or break-down organic N to inorganic (plant-available) N.

Phosphorus, Potassium
Phosphorus (P) and potassium (K) are plant macronutrients. Values reported are for total amounts given in the oxide forms (P_2O_5 and K_2O). These results provide an indication of the nutrient value of the compost sample. However, plant availability of total phosphorus and potassium in compost has not yet been established.

Nitrogen, Phosphorus, Potassium Balance
When compost is applied on the basis of nitrogen (N), most composts will have an excess of phosphorus (P) and potassium (K) relative to crop demand. These mineral elements and salts can accumulate to above optimum levels with repeated application. Growers using compost should regularly soil test to monitor P, K and salt accumulation and should consider using other nutrient sources or nitrogen fixing legumes in their crop rotation especially when P and K levels are above optimum.

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(814) 863-0841 Fax (814) 863-4540
Agricultural Analytical Services Laboratory
The Pennsylvania State University
University Park PA 16802

Analysis Report For:	Copy To:
Jen Sembura 851 Peach Street Lockhart TX 78644	

LAB ID:	SAMPLE ID:	REPORT DATE:	SAMPLE TYPE:	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06635	#D-F : taro(dry)	9/17/2013	Finished Compost		Windrow	

COMPOST ANALYSIS REPORT

EPA 503 Pollutants

Analyte	Results (As is Basis)	Results (Dry Weight Basis)	EPA SW 846 Method
Arsenic (As)	4.9 mg/kg	7.6 mg/kg	3050B + 6010
Cadmium (Cd)	< 0.4 mg/kg	< 0.6 mg/kg	3050B + 6010
Copper (Cu)	14.4 mg/kg	22.6 mg/kg	3050B + 6010
Lead (Pb)	5.9 mg/kg	9.2 mg/kg	3050B + 6010
Mercury (Hg)	0.012 mg/kg	0.019 mg/kg	7473
Molybdenum (Mo)	< 1.1 mg/kg	< 1.8 mg/kg	3050B + 6010
Nickel (Ni)	5.6 mg/kg	8.8 mg/kg	3050B + 6010
Selenium (Se)	< 1.1 mg/kg	< 1.8 mg/kg	3050B + 6010
Zinc (Zn)	45.1 mg/kg	70.6 mg/kg	3050B + 6010

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LAB ID	SAMPLE ID	REPORT DATE	SAMPLE TYPE	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06635	#D-F : taro(dry)	9/17/2013	Finished Compost		Windrow	

COMPOST BIOASSAY
Seedling Emergence and Relative Growth

TEST PARAMETERS	
Test Dates:	09/05/2013 to 09/12/2013
Seed Type:	Cucumber-Marketmore 76 Variety
Media Type: ***(Control)***	STA-Green Smart Soil Potting Mix
Vermiculite:	STA-Green Vermiculite

TEST RESULTS	
Emergence: (% of control)	100.00
Seedling Vigor: (%):	100.00

COMMENTS

INTERPRETATION

The bioassay test provides a screen for the presence of phytotoxins in compost based on seedling emergence and seedling vigor relative to a control. It provides an assessment of compost maturity although should not be used as a stand-alone indicator. The U.S. Compost Council Test Methods for the Examination of Composting and Compost provides the following Maturity Indicator Ratings based on this test.

Maturity Indicator Rating[1]

Test Parameter	Very Mature	Mature	Immature
Emergence %	> 90	80-90	< 80
Seedling Vigor %	> 95	85-95	< 85

[1] Test Methods for the Examination of Composting and Composts

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LAB ID	SAMPLE ID	REPORT DATE	SAMPLE TYPE	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06635	#D-F : taro(dry)	9/17/2013	Finished Compost		Windrow	

RESPIROMETRY
Carbon Dioxide (CO_2) Evolution Rate

TEST RESULTS	
mg CO_2-C/g solids/day:	0.7
mg CO_2-C/g organic matter/day:	2.0

INTERPRETATION

Respirometry (CO_2 Evolution) provides a measurement of the relative microbial activity in a compost and, hence can be used as an estimate of compost stability. The intrepretive index below from the U.S. Compost Council Test Methods for the Examination of Composting and Compost assumes optimal conditions for microbial activity are present including temperature, mositure and nutrients and that toxic components that would inhibit microbial respiration are absent.

Result*	Stability Rating	General Characteristics
< 2	Very Stable	Well cured Compost No continued decomposition No odors No potential for volatile fatty acid phytotoxicity and odor
2-8	Stable	Cured Compost Odor production not likely Limited potential for volatile fatty acid phytotoxicity and odor Minimal impact on soil carbon and nitrogen dynamics
8-15	Moderately unstable, raw compost	Uncured compost Minimal odor production Moderate to high potential for volatile fatty acid phytotoxicity Moderate potential for negative impact on soil carbon and nitrogen dynamics
15-40	Raw compost or raw organic products	Uncured Compost Odor production likely High potential for volatile fatty acid phytotoxicity and odor High potential for negative impact on soil carbon and soil nitrogen dynamics
> 40	Raw feedstocks, unstable material	Raw, extremely unstable material Odor production expected Probably volatile fatty acid phytotoxicity with most materials Negative impact on soil carbon and nitrogen dynamics expected Generally not recommended for use as compost

* Units in mg CO_2-C/g organic matter/day

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LAB ID:	SAMPLE ID:	REPORT DATE:	SAMPLE TYPE:	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06636	#G-I : non treated sargassum	9/17/2013	Finished Compost		Windrow	

COMPOST ANALYSIS REPORT

Compost Test 3A

Analyte	Results (As is basis)	Results (Dry weight basis)
pH	8.1	—
Soluble Salts (1:5 w:w)	1.59 mmhos/cm	—
Solids	74.7 %	—
Moisture	25.3 %	
Organic Matter	23.0 %	30.8 %
Total Nitrogen (N)	1.0 %	1.3 %
Organic Nitrogen[1]	1.0 %	1.3 %
Ammonium N (NH_4-N)	< 3.7 mg/kg *or* < 0.0004 **%**	< 5.0 mg/kg *or* < 0.0005 **%**
Carbon (C)	13.4 %	18.0 %
Carbon:Nitrogen (C:N) Ratio	13.40	13.40
Phosphorus (as P_2O_5)[2]	0.36 %	0.48 %
Potassium (as K_2O)[2]	0.45 %	0.60 %
Calcium (Ca)	4.83 %	6.46 %
Magnesium (Mg)	0.28 %	0.37 %
Particle size (< 9.5 mm)	100.00 %	—

[1]See comments on back of report .

[2]To convert phosphorus (as P_2O_5) into elemental phosphorus (P), divide by 2.29. To convert potassium (as K_2O) into elemental potassium (K), divide by 1.20.

INTERPRETATION

pH pH is a measure of active acidity in the feedstock or compost. The pH scale is 0 (acidic) to 14 (basic) with 7 being neutral. Most finished composts will have pH values in the range of 5.0 to 8.5. Ideal pH depends on compost use. A lower pH is preferred for certain ornamental plants while a neutral pH is suitable for most other applications. pH is not a measure of the total acidity or alkalinity and cannot be used to predict the effect of compost on soil pH.

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Nitrogen, Phosphorus, Potassium Balance When compost is applied on the basis of nitrogen (N), most composts will have an excess of phosphorus (P) and potassium (K) relative to crop demand. These mineral elements and salts can accumulate to above optimum levels with repeated application. Growers using compost should regularly soil test to monitor P, K and salt accumulation and should consider using other nutrient sources or nitrogen fixing legumes in their crop rotation especially when P and K levels are above optimum.

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University Park PA 16802

Analysis Report For:	Copy To:
Jen Sembura 851 Peach Street Lockhart TX 78644	

LAB ID:	SAMPLE ID:	REPORT DATE:	SAMPLE TYPE:	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06636	#G-I : non treated sargassum	9/17/2013	Finished Compost		Windrow	

COMPOST ANALYSIS REPORT

EPA 503 Pollutants

Analyte	Results (As is Basis)	Results (Dry Weight Basis)	EPA SW 846 Method
Arsenic (As)	4.4 mg/kg	5.9 mg/kg	3050B + 6010
Cadmium (Cd)	< 0.3 mg/kg	< 0.5 mg/kg	3050B + 6010
Copper (Cu)	10.3 mg/kg	13.7 mg/kg	3050B + 6010
Lead (Pb)	4.9 mg/kg	6.5 mg/kg	3050B + 6010
Mercury (Hg)	0.012 mg/kg	0.015 mg/kg	7473
Molybdenum (Mo)	< 1.0 mg/kg	< 1.4 mg/kg	3050B + 6010
Nickel (Ni)	4.9 mg/kg	6.5 mg/kg	3050B + 6010
Selenium (Se)	< 1.0 mg/kg	< 1.4 mg/kg	3050B + 6010
Zinc (Zn)	38.5 mg/kg	51.5 mg/kg	3050B + 6010

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LAB ID	SAMPLE ID	REPORT DATE	SAMPLE TYPE	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06636	#G-I : non treated sargassum	9/17/2013	Finished Compost		Windrow	

COMPOST BIOASSAY
Seedling Emergence and Relative Growth

TEST PARAMETERS	
Test Dates:	09/05/2013 to 09/12/2013
Seed Type:	Cucumber-Marketmore 76 Variety
Media Type: ***(Control)***	STA-Green Smart Soil Potting Mix
Vermiculite:	STA-Green Vermiculite

TEST RESULTS	
Emergence: (% of control)	100.00
Seedling Vigor: (%):	100.00

COMMENTS

INTERPRETATION

The bioassay test provides a screen for the presence of phytotoxins in compost based on seedling emergence and seedling vigor relative to a control. It provides an assessment of compost maturity although should not be used as a stand-alone indicator. The U.S. Compost Council Test Methods for the Examination of Composting and Compost provides the following Maturity Indicator Ratings based on this test.

Maturity Indicator Rating[1]

Test Parameter	Very Mature	Mature	Immature
Emergence %	> 90	80-90	< 80
Seedling Vigor %	> 95	85-95	< 85

[1] Test Methods for the Examination of Composting and Composts

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LAB ID	SAMPLE ID	REPORT DATE	SAMPLE TYPE	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06636	#G-I : non treated sargassum	9/17/2013	Finished Compost		Windrow	

RESPIROMETRY
Carbon Dioxide (CO_2) Evolution Rate

TEST RESULTS	
mg CO_2-C/g solids/day:	0.6
mg CO_2-C/g organic matter/day:	2.1

INTERPRETATION

Respirometry (CO_2 Evolution) provides a measurement of the relative microbial activity in a compost and, hence can be used as an estimate of compost stability. The intrepretive index below from the U.S. Compost Council Test Methods for the Examination of Composting and Compost assumes optimal conditions for microbial activity are present including temperature, mositure and nutrients and that toxic components that would inhibit microbial respiration are absent.

Result*	Stability Rating	General Characteristics
< 2	Very Stable	Well cured Compost No continued decomposition No odors No potential for volatile fatty acid phytotoxicity and odor
2-8	Stable	Cured Compost Odor production not likely Limited potential for volatile fatty acid phytotoxicity and odor Minimal impact on soil carbon and nitrogen dynamics
8-15	Moderately unstable, raw compost	Uncured compost Minimal odor production Moderate to high potential for volatile fatty acid phytotoxicity Moderate potential for negative impact on soil carbon and nitrogen dynamics
15-40	Raw compost or raw organic products	Uncured Compost Odor production likely High potential for volatile fatty acid phytotoxicity and odor High potential for negative impact on soil carbon and soil nitrogen dynamics
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* Units in mg CO_2-C/g organic matter/day

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LAB ID:	SAMPLE ID:	REPORT DATE:	SAMPLE TYPE:	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06637	#J-L: treated sargassum	9/17/2013	Finished Compost		Windrow	

COMPOST ANALYSIS REPORT

Compost Test 3A

Analyte	Results (As is basis)	Results (Dry weight basis)
pH	8.4	——
Soluble Salts (1:5 w:w)	1.14 mmhos/cm	——
Solids	57.8 %	——
Moisture	42.2 %	
Organic Matter	21.0 %	36.3 %
Total Nitrogen (N)	0.8 %	1.4 %
Organic Nitrogen[1]	0.8 %	1.4 %
Ammonium N (NH_4-N)	< 2.9 mg/kg *or* < 0.0003 **%**	< 5.0 mg/kg *or* < 0.0005 **%**
Carbon (C)	10.8 %	18.7 %
Carbon:Nitrogen (C:N) Ratio	13.50	13.50
Phosphorus (as P_2O_5)[2]	0.36 %	0.61 %
Potassium (as K_2O)[2]	0.41 %	0.71 %
Calcium (Ca)	3.50 %	6.06 %
Magnesium (Mg)	0.24 %	0.41 %
Particle size (< 9.5 mm)	100.00 %	——

[1] See comments on back of report .
[2] To convert phosphorus (as P_2O_5) into elemental phosphorus (P), divide by 2.29. To convert potassium (as K_2O) into elemental potassium (K), divide by 1.20.

INTERPRETATION

pH pH is a measure of active acidity in the feedstock or compost. The pH scale is 0 (acidic) to 14 (basic) with 7 being neutral. Most finished composts will have pH values in the range of 5.0 to 8.5. Ideal pH depends on compost use. A lower pH is preferred for certain ornamental plants while a neutral pH is suitable for most other applications. pH is not a measure of the total acidity or alkalinity and cannot be used to predict the effect of compost on soil pH.

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C06637	#J-L: treated sargassum	9/17/2013	Finished Compost		Windrow	

COMPOST ANALYSIS REPORT

EPA 503 Pollutants

Analyte	Results (As is Basis)	Results (Dry Weight Basis)	EPA SW 846 Method
Arsenic (As)	4.2 mg/kg	7.2 mg/kg	3050B + 6010
Cadmium (Cd)	< 0.3 mg/kg	< 0.5 mg/kg	3050B + 6010
Copper (Cu)	10.7 mg/kg	18.6 mg/kg	3050B + 6010
Lead (Pb)	3.8 mg/kg	6.5 mg/kg	3050B + 6010
Mercury (Hg)	0.009 mg/kg	0.016 mg/kg	7473
Molybdenum (Mo)	< 0.8 mg/kg	< 1.5 mg/kg	3050B + 6010
Nickel (Ni)	5.4 mg/kg	9.3 mg/kg	3050B + 6010
Selenium (Se)	< 0.8 mg/kg	< 1.5 mg/kg	3050B + 6010
Zinc (Zn)	35.2 mg/kg	60.9 mg/kg	3050B + 6010

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C06637	#J-L: treated sargassum	9/17/2013	Finished Compost		Windrow	

COMPOST BIOASSAY
Seedling Emergence and Relative Growth

TEST PARAMETERS	
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Seed Type:	Cucumber-Marketmore 76 Variety
Media Type: ***(Control)***	STA-Green Smart Soil Potting Mix
Vermiculite:	STA-Green Vermiculite

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Emergence: (% of control)	100.00
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COMMENTS

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The bioassay test provides a screen for the presence of phytotoxins in compost based on seedling emergence and seedling vigor relative to a control. It provides an assessment of compost maturity although should not be used as a stand-alone indicator. The U.S. Compost Council Test Methods for the Examination of Composting and Compost provides the following Maturity Indicator Ratings based on this test.

Maturity Indicator Rating[1]

Test Parameter	Very Mature	Mature	Immature
Emergence %	> 90	80-90	< 80
Seedling Vigor %	> 95	85-95	< 85

[1] Test Methods for the Examination of Composting and Composts

PENNSTATE

(814) 863-0841 Fax (814) 863-4540
Agricultural Analytical Services Laboratory
The Pennsylvania State University
University Park PA 16802

Analysis Report For:	Copy To:
Jen Sembura 851 Peach Street Lockhart TX 78644	

LAB ID	SAMPLE ID	REPORT DATE	SAMPLE TYPE	FEEDSTOCKS	COMPOSTING METHOD	COUNTY
C06637	#J-L: treated sargassum	9/17/2013	Finished Compost		Windrow	

RESPIROMETRY
Carbon Dioxide (CO_2) Evolution Rate

TEST RESULTS	
mg CO_2-C/g solids/day:	0.8
mg CO_2-C/g organic matter/day:	2.3

INTERPRETATION

Respirometry (CO_2 Evolution) provides a measurement of the relative microbial activity in a compost and, hence can be used as an estimate of compost stability. The intrepretive index below from the U.S. Compost Council Test Methods for the Examination of Composting and Compost assumes optimal conditions for microbial activity are present including temperature, mositure and nutrients and that toxic components that would inhibit microbial respiration are absent.

Result*	Stability Rating	General Characteristics
< 2	Very Stable	Well cured Compost No continued decomposition No odors No potential for volatile fatty acid phytotoxicity and odor
2-8	Stable	Cured Compost Odor production not likely Limited potential for volatile fatty acid phytotoxicity and odor Minimal impact on soil carbon and nitrogen dynamics
8-15	Moderately unstable, raw compost	Uncured compost Minimal odor production Moderate to high potential for volatile fatty acid phytotoxicity Moderate potential for negative impact on soil carbon and nitrogen dynamics
15-40	Raw compost or raw organic products	Uncured Compost Odor production likely High potential for volatile fatty acid phytotoxicity and odor High potential for negative impact on soil carbon and soil nitrogen dynamics
> 40	Raw feedstocks, unstable material	Raw, extremely unstable material Odor production expected Probably volatile fatty acid phytotoxicity with most materials Negative impact on soil carbon and nitrogen dynamics expected Generally not recommended for use as compost

* Units in mg CO_2-C/g organic matter/day

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