SARGASSUM IN THE EASTERN CARIBBEAN

A report by students in
Introduction to Pollution (GNM 2261) & Environmental Pollution and Regulation (ENVL 3241)
STOCKTON UNIVERSITY, ENVIRONMENTAL SCIENCE AND GEOLOGY PROGRAMS
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TABLE OF CONTENTS

RELATED RESOURCES IN THIS PACKAGE

1. **Introduction to Sargassum (7 minute video)**
   By Brianna Magner Holly Butella, Marley Deegler and Paige Sorrentino
2. **Introduction to Sargassum (Powerpoint Presentation)**
   By Jacob Simone, Aidan Paez, Daniel Dillon and Priyank Patel
3. **Sargassum Bloom Landings in Barbados**
   By Isabelle Zoccolo (supervised by Dr. Elizabeth Lacey)

GENERAL INTRODUCTION

By John Lombardo

Sargassum (brown seaweed) landings have been growing exponentially every year since 2011. The unsightly mounds of brown seaweed piling up onto the shores has negatively affected tourism in these areas and the costs associated with cleaning it up are nothing short of staggering. For example, Mexico just recently spent $17 million in an effort to remove half a million tons of *Sargassum* from their beaches. The native impacts of *Sargassum* are far reaching. The brown-tides of *Sargassum* cause eutrophication which has been linked to a reduction in marine life, destruction of coral reefs and sustained invasion of kelp forests. The objective of this project is to find a sustainable solution that that will benefit the people of the Eastern Caribbean while saving the fragile marine ecology before even more severe damage is done. To this end, a class project was designed to provide a baseline summary of the current state of knowledge on the problems and the potential benefits associated with *Sargassum*.

The first essay, *"Sargassum Impacts on the Ecosystem"*, is a result of a literature search on studies that shed light on the problems that *Sargassum* presents to the ecosystem and the economic livelihood of the Eastern Caribbean nations. That group evaluated studies that looked into the damage that these blooms have caused to the water quality in the area as well as the negative side effects they have had on the marine life. They also looked into some of the common removal methods that have been utilized and even some of the positive effects *Sargassum* might impact on beaches.

After shedding light on the problem, a second group looked into the potential benefits *Sargassum.* In "*Economic Potential of Sargassum"* the second group went over the wide variety of uses of *Sargassum.* From use as a fertilizer to being refined into a biofuel or even used in pharmaceuticals or cosmetology, *Sargassum* presents opportunities not only for the economies of the Caribbean people, but potentially for mankind in general.

However, focusing on just the positives presents only one side of the coin; another group also did research on the challenges and negative impacts of *Sargassum* in the same area. The chapter, *"Challenges in Using Sargassum"* covers topics that include how *Sargassum* absorbs trace metals and toxins, and how utilizing it for things like fertilizers might not be as cut-and-dry as we would like them to be.

While there is still much research that needs to be done to fully understand and unlock a sustainable solution to the influx of *Sargassum* in the Caribbean, we hope these essays provide you with a clearer understanding of the problem and the potential benefits that could come out of what is currently viewed as a problem. By better understanding the problem, we hope to work towards an end that is beneficial to the people of the Eastern Caribbean and to the increasingly fragile marine ecosystems.

Effect of *Sargassum* on Caribbean Ecosystems

By Ryan Waters & Erica Rush

Summary

Large influxes of *Sargassum* have entered the Caribbean Sea in recent years and plagued coasts with unsightly mounds of brown seaweed. The weed is not only harmful to aesthetics and tourism. The presence of such large amounts of *Sargassum* has had negative impacts on water quality and aquatic organisms in the area. Decomposing *Sargassum* landings (named brown tides) cause eutrophication in the water, leading to dangerously low dissolved oxygen (DO) levels. Researchers have recorded massive deaths in a wide range of fish, crustaceans, mollusks, and other sea life that were exposed to hypoxic conditions brought about by the tides. In addition, high levels of nitrogen, phosphorus, and ammonium were recorded in peak moments of the brown tides. The effects of *Sargassum* have led to high levels of coral reef mortality and replacement of kelp forests with the invasive seaweed. The loss of coral reefs and kelp forests displaces an innumerable number of species that rely on them as habitat and for protection against predators. Species that control native algae on coral such as sea urchins are affected because their primary food source is invaded and replaced by the Pelagic *Sargassum*. Some benefits of the *Sargassum* landings in the Caribbean include improved beach structure, less erosion from wind and waves, the promotion of dune formation, and provision of a valuable habitat for shorebirds and beach scavengers.

Introduction

In aquatic ecosystems, water chemistry is a crucial factor that can determine the life or death of the organisms living there. When factors that are traditionally stable, such as salinity, acidity, and dissolved oxygen, are altered, it is often detrimental to aquatic organisms and can lead to large die-offs. When excess nutrients, specifically nitrogen and phosphorus, make their way into the ocean, the surrounding algal organisms experience a population bloom. In the case of *Sargassum* these blooms are called brown tides, and they have significant effects on the water quality and other organisms in the area. The large landings of brown seaweed that are produced can affect marine and terrestrial animal behavior, but the larger issue occurs when the landings begin to decay. The decaying process of such large amounts of *Sargassum* results in loss of dissolved oxygen in the water column, and the surrounding water can enter oxygen poor (hypoxic) or oxygen deprived (anoxic) conditions (US Department of Commerce, 2019). This process also produces carbon dioxide, which lowers the pH of seawater and leads to hindered growth of fish and shellfish.

Slower growth of sea life results in smaller harvests and more expensive seafood. With the population explosions of species of Pelagic *Sargassum* (co-occurring species of *Sargassum fluitans* and *Sargassum natans)* in the Caribbean in recent years, it is important to analyze the effects that these events have on surrounding water quality and ecosystems as a whole. Unfortunately, the research of *Sargassum*'s impact on Eastern Caribbean ecosystems is lacking. Nonetheless, studies on *Sargassum* impacts from different regions around the world can provide insight into what is happening. Since most of the knowledge gained from those areas is transferrable, there are a few specific impacts we can infer from such studies.

Impact on Water Quality

Research on brown tide events in the West Caribbean has depicted the harm that *Sargassum* landings can have on surrounding ecosystems. Since 2011, the Caribbean Sea has been experiencing massive influxes of *Sargassum* resulting in a buildup of decaying beach-cast material and near-shore brown tides. From 2014-2015, the Mexican Caribbean coast was plagued with brown tides and an influx of nitrates (6150 kg/km) and phosphorus (61 kg/km), resulting in eutrophication. The eutrophication caused a loss of 61.6-99.5% of native belowground biomass (Rodríguez-Martínez, 2016). Near-shore seagrass meadows serve important functions, like maintaining water clarity, aiding in nutrient recycling, reducing exposure to bacterial pathogens, and stabilizing the sediments that wash ashore. The dominant near shore seameadows (*Thalassia testudinum*) have been replaced by calcareous rhizophytic algae and drifting algae.

In 2018, on the Caribbean coast of Mexico, the brown-tide was the largest to-date in the area. Between May and September, a tremendous amount of faunal mortality was observed in tandem with the brown tide. Seventy eight species of aquatic organisms were recorded as victims to the event, and amongst them were mostly fish species. Like other eutrophication events, the brown tide created an environment of low dissolved oxygen that led to hypoxic conditions for aquatic life. The mean value of dissolved oxygen found was 2.9 mg L^{-1}, and most marine organisms are negatively affected at around 4.0 mg L^{-1} (Rodriguez-Martinez 2019). There was also a huge spike of ammonium and phosphorus levels. The values of ammonium and phosphorus were alarmingly higher than typical values for the area. Sulfide was not measured in the samples taken, but it is hypothesized that high levels of hydrogen sulfide (a toxic gas released by the decomposition of *Sargassum*) were also present to cause the high faunal mortality event that was witnessed. These observed effects of the brown tide were widespread along the Caribbean coast, and they could be seen up to 480 meters from the shore.

Similar observations have been made elsewhere. The decomposition of *Sargassum* in other locations throughout the world has been shown to cause hypoxic conditions, the production of hydrogen sulfide (H_2S), and an increase in carbon dioxide production which can, in turn, increase acidity. These changes in critical water quality parameters have serious impacts on dozens of fish and shellfish species, as well as different groups of other organisms, both flora and fauna. It is imperative to conduct baseline studies in affected Eastern Caribbean regions in order to get a better grasp of the severity of the impacts of *Sargassum*.

Other Impacts on Marine Organisms

The arrival of the large masses of *Sargassum* since 2011 has caused changes in the natural dynamics of the Caribbean coastal ecosystems. Stable isotopes were tested to assess the impact of *Sargassum* blooms on the trophic dynamics of *Diadema antillarum* sea urchins. This species is a keystone herbivore to the region and has been affected by the blooms. Sea urchins are considered keystone species in these regions because they play a critical role in maintaining the balance between coral and algae. The effects of the decomposition of the seaweed has caused hypoxic conditions on the reefs and decreased the diversity of the macroalgal food sources typically available to the sea urchins. The dynamics caused by the *Sargassum* influx coupled with the increased organic matter could lead to the reduction in coral reef ecosystem functioning. Mortality of coral reefs can be expedited by the smothering, shading and abrasion of coral by invasive algae. *Sargassum* invasion can also lower the pH of the water and cause coral to develop thinner, more susceptible structures. The loss of coral reefs is detrimental to ecosystems because they provide a number of different benefits such as coastal- storm protection as well as shelter and spawning grounds for a wide range of marine life.

Invasive species of *Sargassum* have become dominant and have replaced the large kelp forests on which many marine animals rely. Hundreds of thousands of species of invertebrates, fish, and algae call kelp forests home. Some species use these areas as spawning grounds or utilize them as protection from predators and storms. The invasion of *Sargassum* and inevitably the replacement of kelp forests with *Sargassum* leads to a decrease in the diversity of organisms in the coastal regions.

The *Sargassum* landings that coat coastal beaches can be as harmful to animals as they are to tourism. Marine turtles, specifically green and loggerhead turtles, have had a number of fatalities in the past attributed to the presence of the *Sargassum* mounds. The thick seaweed makes it more difficult for the turtles to pull themselves ashore and find a suitable nesting spot. The loggerhead turtles, which are physically weaker than the green turtles, saw more fatalities resulting from difficulty moving through the seaweed. In addition, lingering *Sargassum* on the beaches during hatching season can hinder hatchlings and make them even easier targets for predation.

Removal Methods

Large piles of *Sargassum* prevent access to the beach and water, restricting both commercial and recreational use of those areas. The decomposition of dead mats releases unpleasant odor and chemicals that include nutrients, organics and trace metals. Coastal managers are faced with the difficult decision to either remove the *Sargassum* piles or leave them on the beach. One method of removal used in Galveston Island, TX on the Gulf of Mexico, is to rake the piles off the shore line with tractors and deposit them at the base of the dunes. The environmental impacts of raking the *Sargassum* are relatively unknown but some have argued that it causes beach erosion and pollution from the tractors and/or other equipment used. Leaving those racked loads of seaweed on the beach could potential preserves the natural environment. *Sargassum* provides a valuable habitat for foraging shorebirds and beach scavengers (e.g. land crabs, raccoons) and can be beneficial to the beach front. It acts as a sponge during precipitation events as well as hurricane events by absorbing wave energy which protects the sand from wave erosion. The wet piles of seaweed trap sand from wind erosion and the accumulation helps build embryonic dunes that stabilize the beach. It is thought that *Sargassum* deposited at the dunes may enhance dune plant growth. Dune plants retain sand through their roots and above-ground biomass which increases dune stability. Beach dunes provide hurricane protection for coastal population centers. On the upper beach, deposited *Sargassum* is effective in erosion control and may encourage dune formation.

Conclusion

Pelagic *Sargassum* has considerable negative effects on marine organisms and native fauna in the Caribbean Sea. Impacts of the seaweed have resulted in the loss of diversity of organisms in the ecosystem, mortality of coral reefs and degraded water quality. Eutrophication caused by the *Sargassum* deposits is the causation of degraded water quality and loss of marine diversity due to the hypoxic/anoxic conditions it provides. Although *Sargassum* can lead to detrimental effects on water quality, it has some benefits on beaches, mostly stabilizing sandy soils and protecting them from erosion. Such benefits extend to the promotion of dune formation which is critical to coastal regions for protection from storm events. Not much research has been done on the specific ecosystem impacts in the Caribbean region; potential impacts are mostly extrapolated from studies in other parts of the world. More research in the Caribbean region is in order. Research focusing on the specific impacts of sargassum decomposition on other biota and water chemistry is needed.

References

Azanza Ricardo, Julia. (2016). Impacto de la acumulacion de sargazo del Verano del 2015 sobre las tortugas marinas de playa la barca, Peninsula de Guanahacabibes. Revista de Investigaciones Marinas. 36. 52-60.

Cabanillas-Terán, N., Hernández-Arana, H. A., Ruiz-Zárate, M. Á., Vega-Zepeda, A., & Sanchez-Gonzalez, A. (2019). Sargassum blooms in the Caribbean alter the trophic structure of the sea urchin Diadema antillarum. PeerJ, 7, e7589.

Rodríguez-Martínez, R. E., Medina-Valmaseda, A. E., Blanchon, P., Monroy-Velázquez, L. V., Almazán-Becerril, A., Delgado-Pech, B., … García-Rivas, M. C. (2019, June 15). Faunal mortality associated with massive beaching and decomposition of pelagic Sargassum. Retrieved November 1, 2019, from https://www.sciencedirect.com/science/article/pii/S0025326X19304606.

Rodríguez-Martínez, Rosa Elisa; van Tussenbroek, Brigitta I; JordánDahlgren, Eric. 2016. Afluencia masiva de sargazo pelágico a la costa del Caribe Mexicano (2014-2015). In: García- Mendoza, E., Quijano-Scheggia, S. I., Olivos-Ortiz, A. y Núñez-Vázquez, E. J. (eds.), Florecimientos Algales Nocivos en México. Ensenada, México. CICESE. pp. 352- 365.

Silva, Rodolfo, Edgar Mendoza, Ismael Mariño-Tapia, María Luisa Martínez, and Edgar Escalante (2016) An artificial reef improves coastal protection and provides a base for coral recovery. Journal of Coastal Research: Special Issue 75 - Proceedings of the 14th International Coastal Symposium, Sydney, 6-11 March 2016: pp. 467 – 471. https://doi.org/10.2112/SI75-094.1

Tussenbroek, B. I. van, Arana, H. A. H., Rodríguez-Martínez, R. E., Espinoza-Avalos, J., Canizales-Flores, H. M., González-Godoy, C. E., … Collado-Vides, L. (2017, June 23). Severe impacts of brown tides caused by Sargassum spp. on near-shore Caribbean seagrass communities. Retrieved from https://www.sciencedirect.com/science/article/pii/S0025326X17305374.

US Department of Commerce, & National Oceanic and Atmospheric Administration. (2017, October 5). What is eutrophication? Retrieved from https://oceanservice.noaa.gov/facts/eutrophication.html.

Economic Potential of Sargassum

By Jackie Hall, Hannah Dwyer & Katherine Devlin

Summary

There are a variety of uses for *Sargassum* biomass in industries including cosmetology, pharmacology, the food industry, agriculture, mariculture and aquaculture, beach stabilization, remediation, and as a biofuel. Seaweed is a source of antioxidants, plant growth hormones, osmoprotectants, mineral nutrients, and other organic components (Nabti et al., 2016). The usage of this marine algae has been under-utilized as a bioresource. Ironically, *Sargassum* is most effective when it is unwashed/uncleaned, but this has also been linked to salinity problems. Further, since *Sargassum* can bioaccumulate heavy metals and organics, its use may lead to toxicity if not stripped before utilizing it as a bioresource.

***Sargassum* as a biofertilizer**

Many studies have investigated the effectiveness of Sargassum as a plant growth promoter/stimulator. This is due to *Sargassum* being a nutrient-dense macroalgae, rich in minerals, water soluble polysaccharides and phenolic compounds. All these characteristics collectively enhance soil health, quality, productivity and enzymatic activities (Thompson et al., 2019). The use of seaweed as a biofertilizer was considered as it restores nitrogen, phosphorus, and potassium in soils and can be used as a manure (Nabti et al., 2016). Marine algae can be used as a liquid fertilizer, used whole, or fine chopped to form a powder.

There are several extraction procedures used to turn marine algae into a desirable plant biostimulant. The most popular ways include processing water, alkalis, acids, or using low-temperature milling on seaweed to get suspension of fine particles (Nabti et al., 2016).

From there, seaweed is prepared by heating washed seaweed in distilled water or alkaline solutions. Water-extraction is the most cost-effective and practical tool for the release of nutrients from the biomass as washing *Sargassum* has been found to leach some of the nutrients into the surrounding solution (Michalak and Chojnacka, 2015). Chemical analysis of rinsed *Sargassum* samples have confirmed the depletion of N, Na and P, while elevated levels of these essential growth nutrients were measured in the rinse water (Thompson et al., 2019). Since *Sargassum* is most-effective when unwashed, osmotic stress from increased salinity must be monitored to allow for successful crop productivity.

Thompson et al. (2019) examined the impacts of applying *S. johnstonii* to soil on the organic composition and essential minerals levels of Na, Mg, K, Ca and Zn. These mineral levels were found to increase by more than 100-fold. Water retention and soil structure were also found to improve (Thompson et al., 2019). Using *Sargassum* improved growth and early flowering and fruiting of tomato plants. Dune plants were also found to positively respond to raw, unwashed *Sargassum,* mostly as a result of increased nutrient uptake.

A two year study in India examined the effects of different levels of seaweed extract on vegetative flushing and examined the growth patterns of Kesar mangoes. Seaweed extracts containing 3% *Sargassum wightii* significantly increased the number of vegetative flushes, plant growth, and photosynthetic rates (Shankaraswamy et al., 2014).

In the Yucatan Peninsula, local companies have come up with ingenious ways to harvest *Sargassum*. The Ocean Cleaner is one company running a single-boat operation to harvest up to 500 metric tons of *Sargassum* from the sea per day, depending on conditions (Ruiz, 2019). The Ocean Cleaner boat sucks *Sargassum* from the surface, simultaneously filtering out sand. From there, seaweed is dried and passed through a crusher to turn the *Sargassum* into compost (Ruiz, 2019). The compost is mixed with food scraps from the Grand Residences Riviera Cancun, a hotel located in Puerto Morelos (Ruiz, 2019). This is done by the hotel staff and the staff then distributes the *Sargassum* compost as soil for the property's grounds. This has been an increasingly popular initiative for local businesses as the Riviera Maya is estimated to have received 800,000 and 1 million tons of *Sargassum* in 2019 alone (Ruiz, 2019).

A similar study was performed using various seaweeds in vermicomposting (worm composting). *Sargassum swartzi*i was mixed with cowdung (1:1) and vermicomposted using *Perionyx excavatus* for 60 days (Anathavallia et al., 2018). The reduction of organic carbon in vermicomposts ranged from 37 to 51 % depending on seaweed used. Total NPK contents showed significant increment (27–78 %) in vermicompost (Ananthavallia et al., 2018), indicating great promise in *Sargassum* use in vermicomposting.

Sargasso Industrial Association is a collection of five different companies in the private- sector who have been experimenting on turning macroalgae into biofertilizers (Ruiz, 2019). *Sargassum* has been used as a biofertilizer for cocoa, tomato, and sugarcane crops in Mexico (Riviera Maya News, 2019). One study done by Alquimar ® showed that their *Sargassum* biofertilizer increased crop yield by 30 percent (Riviera Maya News, 2019).

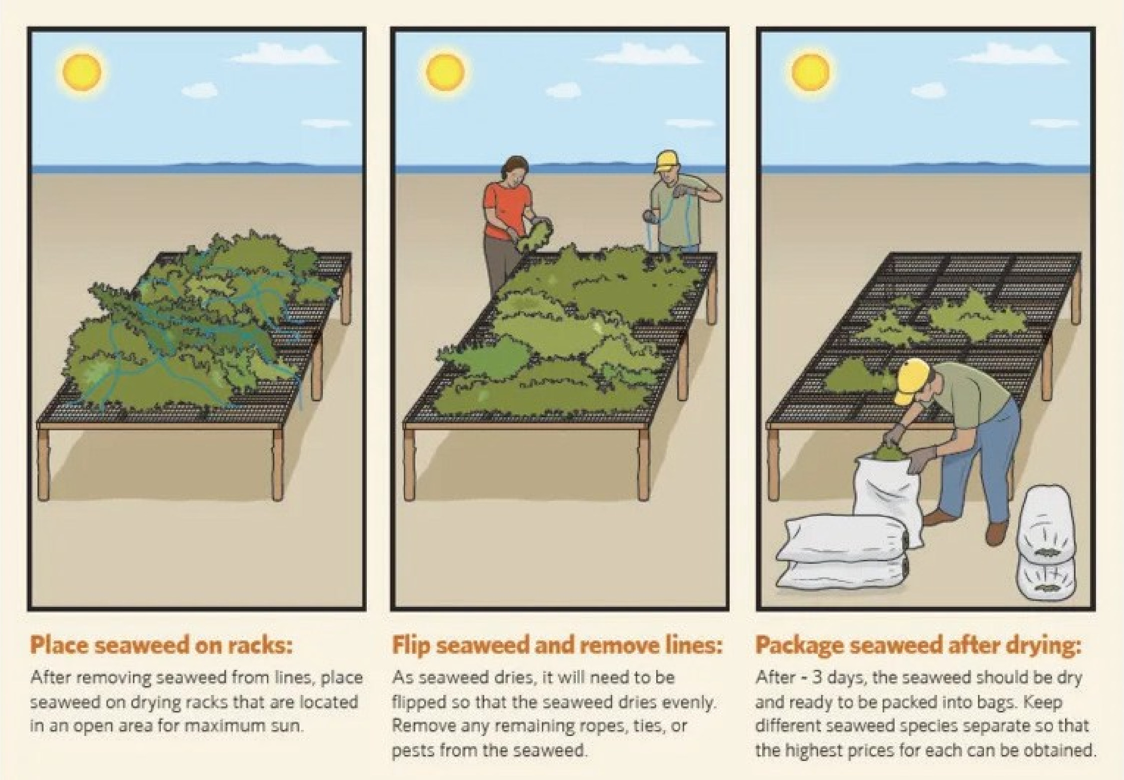
***Sargassum* in mariculture**

In Indonesia, seaweed farming is now a popular commercial enterprise. The cultivation of seaweed was started by the Copenhagen Pectin Factory and has blossomed since that introduction (Marino et al., 2019). Seaweed farming is a form of mariculture, and its advantage is that it has low capital investment. *Kappaphycus* spp and *Eucheuma denticulatum* are red seaweeds that are cultivated widely and used in processed foods (Marino et al., 2019). The seaweed drying process is shown in Figure 1. This study found seaweed farming as a

viable economic activity in this region. Seaweed farming was found to improve socio-economic conditions of farming families as deduced from 81 interviews of farming households in three villages: Sedeoen, Nemberala and Oenggaut (Marino et al., 2019). In this region, 50% of households took part in seaweed farming activities (Marino et al., 2019). Seaweed mariculture in Indonesia has been used successfully with culturing of fish, specifically grouper and carp.

Figure 1: Mariculture seaweed processing

Source: (The Nature Conservancy)



Place seaweed on racks: After removing seaweed from lines, place seaweed on drying racks that are located in an open area for maximum sun.

Flip seaweed and remove lines: As seaweed dries, it will need to be flipped so that the seaweed dries evenly. Remove any remaining ropes, ties, or pests from the seaweed.

Package seaweed after drying: After - 3 days, the seaweed should be dry and ready to be packed into bags. Keep different seaweed species separate so that the highest prices for each can be obtained.

Sargassum in aquaculture

Sargassum has been used in aquaculture operations as a nutrient-sink. Mai et al. (2018) carried out a study to evaluate *Sargassum* nutrient flow in a western king prawn culture and observed lower concentrations of ammonium nitrogen, nitrite-nitrogen, nitrate-nitrogen, dissolved inorganic nitrogen, total nitrogen, phosphate and total phosphorus in waters where *Sargassum* was utilized. These results suggest that integrating *Sargassum* into western king prawn culture can benefit prawn farming by assisting in the maintenance of optimum water quality and improve environmental conditions (Mai et al., 2018).

Sargassum in the food industry

Traditionally, *Sargassum spp*. is consumed widely in Japan and Korea. In China, 32,000 tons of seaweed is collected per year for commercial cultivation (Zou et al., 2014), and up to a dozen species of seaweed are used. The quantities are even larger in Japan. After harvesting, the plant is dried and cut into strips. It can also be powdered and then used in the preparation of soups, beans and fish and meat dishes. It can also be paired with rice as a vegetable.

Unlike other seaweeds, *Sargassum* lacks carrageenan, commonly used in the food industry as a binding agent. In Japan, 10% of the daily dietary needs can be met by consuming *Sargassum* raw or in soups (Thompson et al., 2019). These seaweeds are rich in dietary fiber, more so than brown rice or lentils (Thompson et al., 2019). This is why they are often combined with beans to improve digestibility as well as supplement nutrients. *Sargassum* is low in fatty acids and enriched with protein (Thompson et al., 2019). Some varieties are rich in glutamic acid and can act as a substitute for monosodium glutamate and a flavor-enhancer. Other significant food seaweed species in Japan include Nori (*Porphyra*) and Kombu

(*Laminaria* and *Saccharina*) and Wakame (*Undaria pinnatifida*).

***Sargassum* in pharmacology**

Sargassum metabolites have a wide range of properties, including antibiotic, anti-inflammatory, anticoagulant, anticonvulsant, anti-HIV, antitumor, and antineoplastic (Ayyad et al., 2011). In a study done by King Abdul Aziz University, four *Sargassum* metabolites, fucosterol, saringosterone, saringosterol, and fucoxanthin were investigated to test for pharmacological activity. These metabolites were extracted with an equal mixture of Pet. ether, chloroform, and methanol from air dried *Sargassum* and fractionated with different adsorbents. Two pure materials were tested for protection of DNA from damage, antioxidant, antitumor, and cytotoxicity (Ayyad et al., 2011). Fucoxanthin was found to be an antioxidant and possess cytotoxic properties against breast cancer. This shows the potential of *Sargassum* to be used as an antioxidant or utilized in antitumor treatments.

***Sargassum* in cosmetology**

Sargassum is also being used in cosmetic products, specifically skin creams and moisturizers. Extracts from different species of algae offer different benefits, such as moisturization, anti-wrinkling, anti-aging, and anti-inflammatory (Pereira, 2018). 221 species of seaweed have high commercial value, with brown seaweed being a highly cultivated variant (Pereira, 2018). These species have been found to be rich in antioxidants which makes them valuable to the cosmetic industry.

In order to obtain sodium alginate, the seaweed first goes through a process called extraction, where the seaweed receives an acid pretreatment and is then treated with an aqueous alkali solution. The extract is then precipitated, forming alginic acid, before undergoing conversion and purification. The result is a dry, powdered sodium alginate. Bioactive extracts from algae create many products for anti-ageing, skin whitening, and pigmentation reduction (Pereira, 2018). There are also studies that show some secondary metabolites of algae protect against UV rays (Pereira, 2018). In recent decades, the use of seaweed for cosmetics or cosmeceuticals has become much more pronounced. Some companies air-dry the seaweed and use the dried pieces in their products while others simply extract the nutrients, vitamins, or chemicals they want for their product.

Research with *S. natans* has shown that multistage extraction and precipitation provides a higher yield and purity of sodium alginate than the commonly-used single stage processing. The final extract was comparable to a commercial brand of sodium alginate (Mohammed, 2018). Another study seeking to optimize the process of extracting the polysaccharide fucoidan from *S. fusiforme* found that ultrasonic assisted enzymatic hydrolysis with cellulase has benefits over hot water extraction and acid extraction. Acid extraction can damage the polysaccharide, while both are time consuming with a low polysaccharide extraction rate. Under optimal conditions, the optimized method resulted in a fucoidan extract that had a better moisture retention rate than glycerin, butanediol, and sodium alginate. This extract could be used as a moisturizer in skin-care products (Lui, 2018).

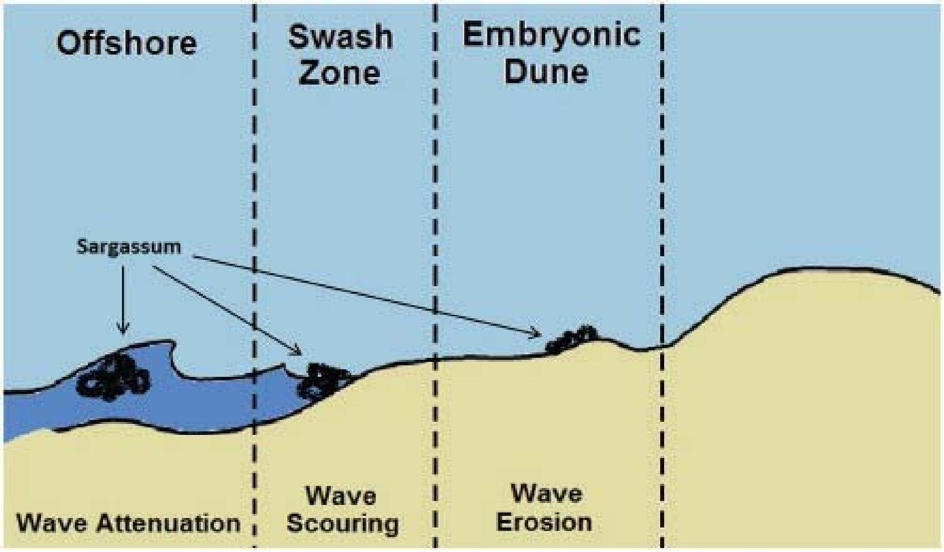
Sargassum in beach stabilization

The main concern about *Sargassum* is that it smells bad, hurts tourism, and negatively impacts organisms, including sea turtles. On beaches, management practices are ongoing to rake *Sargassum* with heavy machinery and deposit it at the base of dunes (Williams, 2007).

This is done for two species of *Sargassum*, *fluitans* and *natans*. Low-nutrient sediments and raking of dunes make it difficult for plants to establish on dunes. In Texas, the Galveston Island Park Board of Trustees (GIPBT) implemented the *Sargassum* Policy Committee to develop beach cleaning processes (Williams, 2007). One study analyzed the effects of *Sargassum* deposits and the dune plant known as *Panicum amarum*. The results showed that adding washed *Sargassum* increased plant growth on dunes. *Sargassum* patches were found to trap sand from wind erosion. This allows for an accumulation of sand to be present around patches of *Sargassum*, building small dunes in the process, which help stabilize the beach. The nutrients within *Sargassum* also act as a natural source of fertilizer for the colonizing vegetation. This is advantageous in beach settings where erosion is of concern. *Sargassum* mats can be cut up to establish walkways for beachgoers. These paths can be designed to protect the dunes and not disturb tourism.

Similarly, another study examined *Sargassum*'s impact at different locations on a cross- shore profile. Three zones were identified (Figure 2). *Sargassum* can be used to effectively mitigate beach erosion as sea level rises and attenuate the stress in coastal communities caused by storms, whose frequency and intensity is increasing (Innocenti et al., 2018). The results from this study indicate *Sargassum* is a viable resource to use for beach maintenance, leading to 12% wave attenuation, 46% scouring velocity reduction, and 103% dune erosion reduction (Innocenti et al., 2018). Light coverings of *Sargassum* reduced embryonic dune erosion by 6% when compared to the control. These clearly show the benefits of using macroalgal wracks as a tool to combat sediment loss on beaches.

Figure 2: Use of *Sargassum* in dune stabilization



Source: (Innocenti et al., 2018)

Sargassum as a biofuel

Further evidence indicates seaweeds show promise as feedstock for biofuels due to their fast growth, large biomass yields, high carbohydrate content, and the fact that no land is needed for growth. *S. muticum*, one seaweed that is invasive to both Europe and North America, has been tested for its use as a third generation biofuel because it has a high protein content that allows fermentation to occur without the inclusion of additional nutrients. Analysis has shown that non-isothermal auto-hydrolysis, heating the raw material by high temperature water, is an effective pretreatment with fewer environmental consequences from additional materials. The combination of *S. muticum* with other biomass can be a more cost-effective method of ethanol production, since it both increases ethanol concentration and avoids nutrient addition (Del Rio, et al., 2019).

In a separate study, *Sargassum* used in a mono-digestion was found to be unsustainable for energy extraction given its low bioconversion efficiency and unpredictable influx volume (Thompson et al., 2019). In contrast, the co-digestion of *Sargassum* combined with organic municipal solid waste was found to be energetically advantageous, potentially enhancing energy recovery by 5-fold (Thompson et al., 2019). However, the biogas generated in this process was found to contain hydrogen sulfide which has corrosive properties. If uncontrolled, this gas could cause engine damage and failure (Thompson et al., 2019).

***Sargassum* in biological remediation (phytoremediation)**

Sargassum has been found to contain four heavy metals: lead, copper, zinc, and manganese (Vijayaraghavan et al., 2008). *Sargassum* preferentially absorbs lead, followed by copper, zinc, and lastly manganese (Vijayaraghavan et al., 2008). Using different biosorption dosages revealed that *Sargassum* had good biosorption capacity of high metal removal at 3 g/L. Applying *Sargassum* to real stormwater runoff revealed *Sargassum* biomass being capable of removing heavy metal ions (Vijayaraghavan et al., 2008). This study was performed in Singapore where *Sargassum* was collected from beaches. The *Sargassum* was then extensively washed with deionized water and sun-dried before being blended. The stormwater was collected from a drain near a residential area in Singapore, where it was stored in plastic bottles. From here, the biosorption capacity of *Sargassum* was analyzed. pH was found to severely impact the metal uptake capacity, with optimal uptake occurring at pH 6. The biosorption rate was fast, the slowest sample taking 50 minutes to extract metal ions. Overall, the process was completed within 20 minutes. This means *Sargassum* could be useful in water treatment system designs.

Although slightly inferior to synthetic metal solutions for treatment, *Sargassum* biomass was found to be optimal for the removal of metal ions present in low concentrations (Vijayaraghavan et al., 2008). Further studies show how residues, which are a waste product of alginate extraction, have been tested to evaluate the amount of toxic metals that these specific algae are capable of absorbing. *S. filipendula* was submitted to two rounds of alginate extraction before the residues were tested. All of the tested toxic metals showed adequate absorption rates, though cadmium had the greatest reduction in removal. The use of residues to absorb toxic metals, possibly on an industrial level, adds a further level of use for *Sargassum* (Cardosa, et al., 2019).

Another study examined found that *Sargassum* along with its alginate extraction products were able to be used as biosorbents for nickel (II) and copper (II) ions (Barquilha et al., 2018). Biosorption occurred rapidly in aqueous solutions. Equilibrium was achieved between one and half and six hours. Calcium alginate beads were found to have the highest biosorption capacity for these ions (Barquillha et al., 2018). The greatest factor for metal uptake in this study was the pH of the solution used. This suggests *Sargassum* and its extraction products have potential to be used successfully for biological remediation of heavy metals via phytoextraction or phytoaccumulation.

Heavy metals in *Sargassum*

Many organisms hyperaccumulate heavy metals which can go up the trophic level. A study in China looked at the factors that affect heavy metal and stress tolerance in *Sargassum* by examining oxidation stress under acute and chronic conditions (Zou et al., 2014). In this study, *Sargassum* was collected from Wenzhou, China and the metabolic differences between responses of *S. fusiforme* to acute and chronic copper (Cu) exposures was determined (Zou et al., 2014). Lipid peroxidation is the process of oxidized degradation of a lipid which results in cell damage. Antioxidants may inhibit this process. Liquid peroxidation was based on the content of malondialdehyde (MDA) present in samples. Antioxidant enzyme activity was determined by examining superoxide dismutase (SOD), catalase (CAT) and peroxidase (POD). CAT is associated with antioxidant stress in algae. The activity of nitrate reductase (NR) was measured as this enzyme is involved in the maintenance of optimal cellular redox potential (Zou et al., 2014). Overall, there was a decrease in the total amount of the predominant amino acids, including alanine, glutamate, glutamine and aspartate under acute Cu stress (Zou et al., 2014). Under chronic Cu stress, all the predominant amino acids increased. Further, nitrate metabolism was drastically impacted under chronic Cu stress which influenced enzyme metabolism. As a result, the levels of primary amino acid products of nitrogen assimilation were reduced (Zou et al., 2014). The physiological response to increased Cu stress led to lipid peroxidation, indicating phytotoxic conditions in *Sargassum*. Cell permeability was also impacted under chronic Cu stress. These results suggest *Sargassum* is negatively impacted by chronic heavy metal absorption. However, studies have been successful in stripping low concentrations of heavy metals from *Sargassum* biomass. One way heavy metals were removed from *Sargassum* was by increasing salinity (Thompson et al., 2019).

Economic feasibility of *Sargassum* products in the Caribbean:

Sargassum appears almost everywhere on the Caribbean coast so it is possible to harvest it almost anywhere in that area. In Mexico, hoteliers are worried about the effect

Sargassum will have on tourism. According to data from Mexico, some areas "lost an estimated $12 million in 2019 from cancellations related to *Sargassum*" (Webber, 2019). The cleanup of *Sargassum* requires machinery so it is not an easy task; the process interferes with tourism, leading to reduced income. Some hotel owners in Mexico say that the cost of keeping the beaches clean has become "unsustainable" as they are spending approximately "$47,000 US dollars a month to ensure that beaches meet the expectations of tourists" (Reza et al., 2019). David Ortiz, the Tulum Hotel Association President, proposed that the government design a "new tax" to alleviate this pain on hotel owners and operators, arguing that "hotel owners would be prepared to pay a special *Sargassum* tax if they knew that their money would be used wisely" (Reza et al., 2019).

References

Ananthavallia, R., Ramadasb, V, Arockia, J., Paula, J., Karunai, B and S. Natchimuthu. (2018) Seaweeds as bioresources for vermicompost production using eartworm, Perionyx excavates. 275:394-401

Ayyad, S.-E. N., Ezmirly, S. T., Basaif, S. A., Alarif, W. M., Badria, A. F., and F.A. Badria. (2011). Antioxidant, cytotoxic, antitumor, and protective DNA damage metabolites from the red sea brown alga Sargassum sp. Pharmacognosy Research 3(3): 160-165. https://doi-org.ezproxy.stockton.edu/10.4103/0974-8490.85000

Barquilha, C., Cossich, E., Tavares, C., Silva, E. (2018). Biosorption of nickel(II) and copper(II) ions by *Sargassum* sp. in nature and alginate extraction products. Volume 5, February 2019, Pages 43-50.

Cardosa, S.L., Costa, C.S.D., Nishikawa, E., da Silva, M.G.C., Vieira, M.G.A. (2017). Biosorption of toxic metals using the alginate extraction residue from the brown algae *Sargassum filipendula* as a natural ion-exchanger. *Journal of Cleaner Production, 165,* 491-499. http://dx.doi.org/10.1016/j.jclepro.2017.07.114

Del Río, P.G., Domínguez, E., Domínguez, V. D., Romaní, A., Domingues, L., Garrote, G. (2019). Third generation bioethanol from invasive macroalgae *Sargassum muticum* using autohydrolysis pretreatment as first step of a biorefinery. *Renewable Energy, 141,*728-735. https://doi.org/10.1016/j.renene.2019.03.083

Lui, B., Lui, X., Wu, F., Cao, G., Zhang, C., Yang, J. (2018). Extraction process optimization and moisturizing performance of fucoidan from *Sargassum fusiforme*. *Medical Plant, 9*(3), 21-24,30. Doi:10.19600/j.enki.issn2152-3924.2018.03.006

Innocenti, R., Feagin, R., Huff, T. (2018). The role of *Sargassum* macroalgal wrack in reducing coastal erosion. Retrieved from https://www.sciencedirect.com/science/article/pii/S0272771418301100

Nabti, E., Jha, B., Hartmann, A. (2016). Impact of Seaweeds on Agricultural Crop Production as BioFertilizer. Retrieved 23 October 2019.

Mai, H., Fotedar, R., Fewtrell, J. (2018). Evaluation of *Sargassum* sp. as a nutrient-sink in an integrated seaweed-prawn (ISP) culture system. Retrieved 9 December 2019 from https://doi-org.ezproxy.stockton.edu/10.1016/j.aquaculture.2010.09.010

Reza, A., Meraz, F. (2019, July 4). Huge *Sargassum* arrival blankets beaches of southern Quintana Roo. Retrieved 10 December 2019 from https://mexiconewsdaily.com/news/huge-*Sargassum*-arrival-blankets-beaches/.

Riviera Maya News. (2019). Local Companies Markets Biofertilizer from Sargasso. Retrieved 23 October 2019. Retrieved at https://www.riviera-maya-news.com/local-company-markets-biofertilizer-from-sargasso/2019.html

Ruiz, V. (2019). How to Handle a Massive Seaweed Invasion. Retrieved 23 October 2019.

Sembera, J., Meier, E., Waliczek. (2018). Composting as an Alternative Management Strategy for *Sargassum* Drifts on Coastlines. Retrieved 1 November 2019.

Shankaraswamy, J., Chovatia, R. S. (2014). Effect of seaweed (*Sargassum* WightII) extract,6-BA, chemical nutrients and pruning on vegetative growth cycle of mango (mangifera indica L.) CV. kesar. The Journal of Plant Science Research, 30(1), 107-111. Retrieved from https://login.ezproxy.stockton.edu/login?url=https://search-proquest.com.ezproxy.stockton.edu/docview/1552482980?accountid=29054

Thompson, T., Young, B., Baroutian, S. (2019). Pelagic *Sargassum* for energy and fertiliser production in the caribbean: a case study on barbados. Retrieved from https://www.sciencedirect.com/science/article/pii/S1364032119307725

Marino, M., Breckwoldt, A., Teichberg, M., Kase, A., Reuter, H. (2019). Livelihood aspects of seaweed farming in Rote, Island, Indonesia

Michalak I., Tuhy L., Chojnacka, K. (2015). Seaweed extract by microwave assisted extraction as plant growth biostimulant. Open Chem 13:1183–1195.

Mohammed, A., Bissoon, R., Bajnath, E., Mohammed, K., Lee, T., Bissram, M., … Ward, K. (2018). Multistage extraction and purification of waste *Sargassum natans* to produce sodium alginate: an optimization approach. *Carbohydrate Polymers, 198,* 109-118.

https://doi.org/10.1016/j.carbpol.2018.06.067

Pereira, L. (2018). Seaweeds as Source of Bioactive Substances and Skin Care Therapy—Cosmeceuticals, Algotheraphy, and Thalassotherapy. Cosmetics, 5(4), 68.Webber, J. (2019, July 3). Mexican tourist industry counts cost as seaweed covers beaches. Retrieved 10 December 2019 from https://www.ft.com/content/80e09a68-9b88-11e9-9c06-a4640c9feebb.

Williams, M., Rusty, A. *Sargassum* and beach erosion: potential costs and benefits for coastal Managers. (2007). Retrieved 1 November 2019.

Williams, A. & Feagin, R. Environmental Management (2010) 46: 738. https://doi-org.ezproxy.stockton.edu/10.1007/s00267-010-9558-3

Vijayaraghavan, K., Teo, T., Balasubramanian, R., Joshi, U. (2008). Application of *Sargassum* biomass to remove heavy metal ions from synthetic multi-metal solutions and urban stormwater runoff. Retrieved 1 November 2019.

Zou, H., Pang, Q., Lin, L., Zhang, A., Li, N., Lin, Y., . . . Yan, X. (2014). Behavior of the edible seaweed *Sargassum* fusiforme to copper pollution: Short-term acclimation and long-term adaptation. PloS One, 9(7), 1. doi:http://dx.doi.org.ezproxy.stockton.edu/10.1371/journal.pone.0101960

Challenges in commercial use of *Sargassum*

By Scott McClary & Mike Herrick

Summary

To combat the surge of *Sargassum natans* and *Sargassum fluitans*, the most common species of *Sargassum* in the Caribbean, the island governments are considering plans of using *Sargassum* as a soil amendment, a fertilizer (*Sargassum*, CAST). However, there is uncertainty over its safety due to potential contaminants contained within. If the *Sargassum* is processed into fertilizer, the contaminants could bioaccumulate into products, including food. If these harmful heavy metals are in the *Sargassum*, the question is whether they are in high enough quantities to warrant caution and/or if they can be removed. First, we look at what *Sargassum* can absorb and in what quantities. Second, what problems are presented by the chemicals absorbed by Sargassum and how can they be addressed.

Chemical Absorption by *Sargassum*

Sargassum is very absorbent and it can absorb multiple types of different heavy metals, toxic contaminants and organics. These metals include, in no specific order, Mg, Pb, Cd, Ni, Cr, Cu, Sr, and other toxic chemicals like As. All these contaminants have been shown, through different studies, to accumulate in *Sargassum* in different quantities. One study looked into the concentrations of Cu, Pb, and As in *Sargassum pallidum* in the Dana Bay region. For Cu, the average concentration was found to be just under 4 mg g^{-1}. That for Pb was about 7.4 mg g-1 and As, 122 mg g^{-1} (Miao, 2014). Another study recorded *Sargassum's* absorption of Sr, focusing on how long it takes for it to reach equilibrium. In that study, conducted near a nuclear power plant in Brazil, it took *Sargassum* 3 days to reach equilibrium with the surrounding water (Freitas, 2016). Another study found that the maximum uptake level of cadmium is 120 mg g^{-1}. This study was done by collecting seaweed near the Northeastern coast of Brazil (Cruz, 2004). A different study found the maximum absorption of Nickel in *Sargassum* at 70 mg g ^{1}. This study was done on *Sargassum muticum* in Cuba (Bermudez, 2011). A study on *Sargassum fluitans* showed maximum Uranium adsorption capacity exceeding 560 mg g^{-1} at pH 4, 330 mg g^{-1} at pH 3.2 and 150 mg g^{-1} at pH 2.6 (Yang, 2019). These studies demonstrate the potential of *Sargassum* to clean up polluted waters through phytoextraction. More studies need to be done to determine the extent of pollution in Caribbean waters and the specific chemical pollutants involved. The following table (Table 1) summarizes the literature on recorded levels of different contaminants in the Caribbean region.

While there is extensive research and findings on the absorbance of trace metals and elements for *Sargassum*, there has been little research done on *Sargassum's* absorption of organic matter. A study in the Australian Great Barrier Reef showed that *Sargassum* supplemented their nutrient supply with metabolites from organic particulate matter instead of their usual food source. The study also showed a positive correlation between growth rates of *Sargassum*, and the presence of organic particulate matter (Schaffelke, 2002). There are signs in the region of organic matter being released into the Caribbean. There are multiple sources of organic pollution. One study found that sewage might be the most widespread and problematic source of organic pollution in the Caribbean. This is due to the lack of capital for proper waste disposal and sewage infrastructure to deal with sewage and other liquid effluents (Siung-Chang, 1997).

Table 1: Results of the literature review on Caribbean metal water quality concentrations (Fernandezet al., 2007)

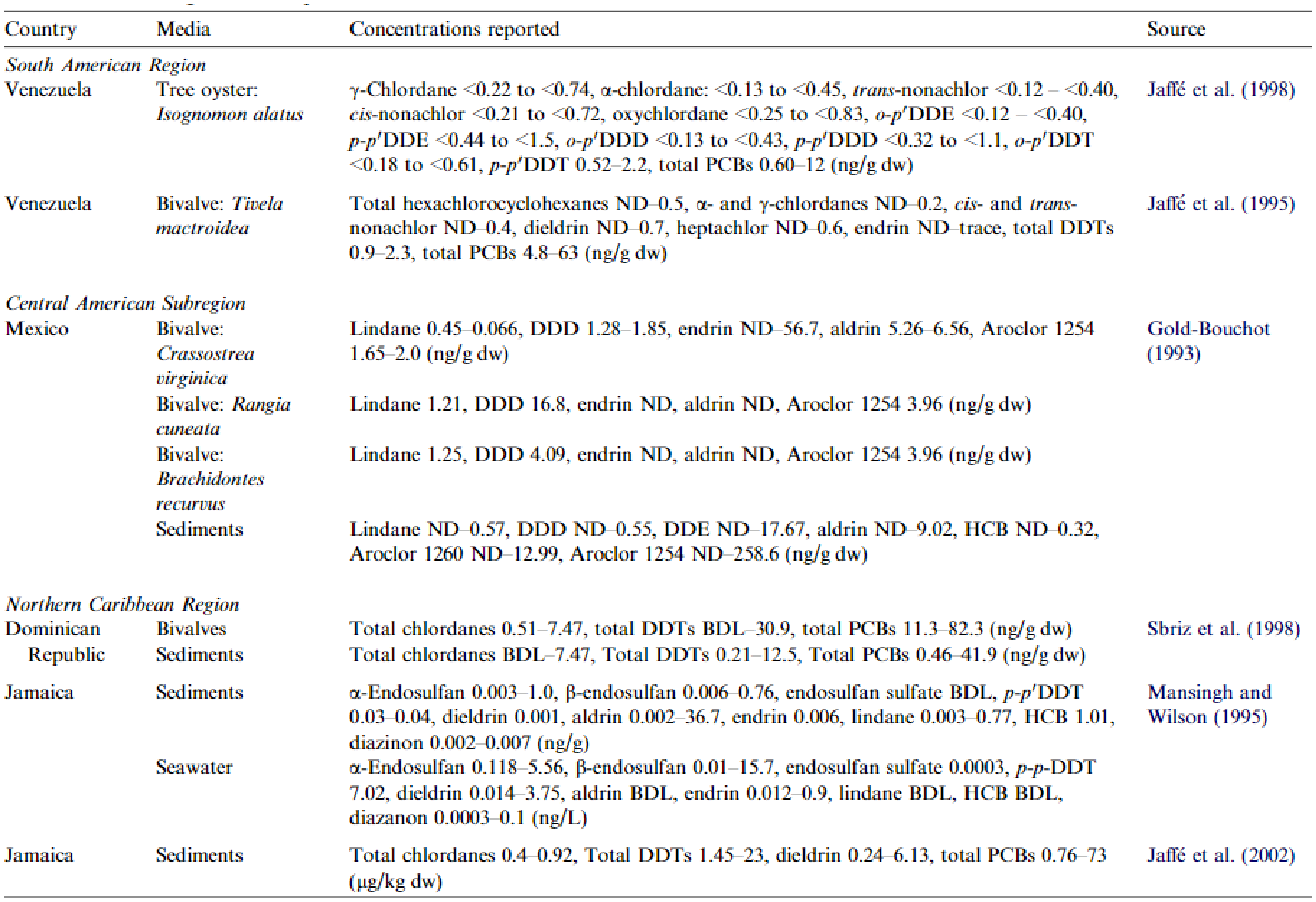
Country	Media	Concentrations reported	Source
South American Region			
Colombia	Fish: *Mugil incilis*	Hg DL-166 (μg/kg dw)	Alonso et al. (2000)
	Fish: *Eugerres plumier*	Hg DL-852 (μg/kg dw)	
	Sediment	Hg 20–10,293 (μg/kg dw)	
Venezuela	Coral: *Porites astreoides*	Al 1.44–846.49, Fe nd–369.31, Cu 3.33–89.57, Zn 0.83–42.45, Cr 0.16–23.9, Pb 0.029–4.74 (μg/g dw)	Bastidas and Garcia (1999)
Venezuela	Echinoderm: *Holothuria mexicana*	Al 0.0–711.7, Cu 47.5–3043.2, Mn 0.0–40.5, Ni 0.0–224.5, Pb 49.4–1334.7, Zn 17.5–2165 (ppm dw)	Laboy-Nieves and Conde (2001)
	Echinoderm: *Isostichopus badionotus*	Al 20.8–543.1, Cu 59.0–3854.0, Mn 0.0–46.8, Ni 0.0–219.8, Pb 73.7–2018.6, Zn 14.6–4472.5 (ppm dw)	
Venezuela	Bivalve: *Isognomon alatus*	Cd 0.33–0.91, Cr 0.46–1.2, Cu 14–49, Ni 11–18, Pb 0.4–0.71, Zn 0.25–2.1 (μg/g dw)	Jaffé et al. (1998)
Venezuela	Bivalve: *Tivela mactroidea*	Cd 2.2–3.3, Cr 1.6–4.6, Cu 58.9–152, Ni 12.0–30.7, Pb 2.0–3.1, Zn 226–266 (μg/g dw) Ba	Jaffé et al. (1995) and Alfonso et al. (2005)
Trinidad and Tobago	Sediments	Fe 12.39–15,716, Cu 0.06–15.95, Cd 0.04–2.12, Pb 0.30–20.91, Zn 0.10–39.29 (μg/g dw)	Rajkumar and Persad (1994)
	Seawater	Fe 0.96–1703, Cu 0.50–14.27, Cd 0.06–1.13, Pb 0.50–6.94, Zn 0.50–92.23 (μg/L)	
Trinidad and Tobago	Seawater	Fe 16.01–114.27, Cu 1.5, Ni 2.33–2.88, Zn 5.9–29.66, Mn 4.6–57.8 (ppb)	Rajkumar et al. (1995)
Trinidad and Tobago	Sediments	Fe 1.08–29.45, Cu 120–421, Cr 3.08–42.82, Mn 5.70–32.28, Ni 2.35–30.49, Pb nd–4.90, Cd 1.88–67.90 (ppm dw)	Hall and Chang-Yen (1986)
Central American Region			
Costa Rica	Coral: *Siderastrea siderea*	Al 313.0, V 44.7, Cr 7.3, Mn 7.3, Fe 113.2, Ni 91.6, Cu 2.0, Zn 10.2, Cd 7.5, Pb 31.0 (mean, ppm dw)	Guzman and Jimenez (1992)
	Sediments	Al 9261.1, V 153.7, Cr 19.1, Mn 303.8, Fe 4868.6, Ni 100.5, Cu 8.7, Zn 19.6, Cd 5.9, Pb 28.6 (mean, ppm dw)	
Costa Rica	Coral: *Siderastrea siderea*	Hg 15.2 (mean, ppm dw)	Guzman and Garcia (2002)
	Sediments	Hg 85.9 (mean, ppm dw)	
Mexico	Oyster: *Crasostrea virginica*	Cd 3.8–4.4, Cu 284–380, Fe 725–1128, Mn 36–44, Pb 7.5–12.4, Zn 426–759 (mean, mg/kg dw)	Vasquez et al. (1993)
Mexico	Coral: *Montastraea annularis*	Pb 12–85 (nmol Pb/mol Ca)	Medina-Elizalde et al. (2002)
Panama	Coral: *Siderastrea siderea*	Al 250.7, V 41.8, Cr 9.9, Mn 6.9, Fe 70.8, Ni 93.7, Cu 3.8,Zn 8.9, Cd 7.6, Pb 32.3 (mean, ppm dw)	Guzman and Jimenez (1992)
	Sediments	Al 4094.6, V 66.0, Cr 9.2, Mn 171.0, Fe 1705.6, Ni 93.1, Cu 4.1, Zn 15.8, Cd 7.0, Pb 33.2 (mean, ppm dw)	
Panama	Coral: *Siderastrea siderea*	Hg 21.4 (mean, ppm dw)	Guzman and Garcia (2002)
	Sediments	Hg 62.0 (mean, ppm dw)	
Northern Caribbean Region			
Cuba	Sediment (<63 μm)	Cr 22–339, Cu 18–716, Hg 0.64–76, Mn 79–251, Ni 11–112, Pb 44–903, Zn 72–3736 (μg/g dw)	Gonzalez and Torres (1990)
Cuba	Sea urchin: *Echinometra lucunter*	Al 1.2–39, Cr 3.6–8.3, Cu 0.58–2.9, Fe 49–129, Mn BDL–0.90, Ni BDL–3.0, Zn 163–412 (μg/g dw)	Gonzalez et al. (1999)
Cuba	*Rhizophora mangle* leaves	Fe 24–342, Ni BDL–23.6, Mn 82–297, Zn 2.2–4.7 (μg/g dw)	Gonzalez and Ramirez (1995)
	Sediments	Pb 4.6–9.6, Cu 4.1–28, Zn 7.9–129, Co 7.7–327, Fe 0.64–22.66%, Mn 125–2957, Ni 69–4764 (μg/g)	
Dominican Republic	Bivalves	Al 3.80–2240, Cd 0.04–2.57, Cr 1.66–10.7, Cu 3.08–866, Fe 50.9–3400, Hg 0.29–7.02, Ni 1.25–7.92, Pb 0.09–1.49, Zn 22.9–4380 (μg/g dw)	Sbriz et al. (1998)
	Sediments	Al 276–33,000, Cd 0.028–0.435, Cr 8.88–186, Cu 1.01–111, Fe 230–48,700, Hg 0.096–0.565, Ni 1.71–124, Pb 0.42–81.8, Zn 2.34–244 (μg/g dw)	
Jamaica	Sediments (<63 μm)	Al 0.10–6.49%, Fe 0.12–3.67%, As 0.84–10.3, Sb 0.15–1.20, V 7.8–105, Cr 16.6–53.1, Mn 33–649, Co 0.75–13.0 (ppm)	Greenaway and Rankine-Jones (1992)
Jamaica	Sediments	V 6.6–112, Cr 5.0–48.0, Co 0.68–16.1, Ni 3.7–23.9, Cu 3.5–73.8, Zn 7.9–70.0, As 1.4–7.03, Cd nd–10.0, Pb 6.4–31.1, Hg 0.05–0.30 (mg/kg dw)	Jaffé et al. (2002)
Eastern Caribbean Region			
Guadelupe	Sediments	Pb 1.7–235.7, Zn 19–664.3, Cu 9.3–187.2, Cd <0.3 to 0.6 (μg/g dw)	Bernard (1995)

Another source is the increase of petroleum hydrocarbons in the region. The Caribbean is one of the largest oil producing areas in the world. Five million barrels are transported through the region every day and that discharges due to tank washing is estimated to be about seven million barrels each year. This estimated was derived from sediment studies in the region (Botello, 1991). Table 2 is compiled from a literature review of different studies that analyzed different organic pollutants in the Caribbean region (Fernandez et al., 2007). Could organics be enhancing Sargassum growth in the Caribbean? More studies are needed to answer this question.

The pH of the water plays an important role in determining metal absorption by *Sargassum*, with absorption reaching its peak for moderately acidic waters for most metals (e.g. pH 4 for Pb). Managing ocean acidification can help reduce metal absorption by *Sargassum* (Vieira, 2017). Little research exists on the impact of specific soil parameters on organic matter absorption and metabolism by *Sargassum*.

An important consideration is whether *Sargassum* could absorb metals and organics in concentrations that are considered harmful to human health. It has already been shown in other parts of the world that some species absorb chemicals in harmful levels. There are cases of contaminant levels reaching these levels in other parts of the world. For example, both *Undaria pinnatifida* and *Sargassum muticum,* were shown to contain relatively high levels Fe, Zn, Cu, Mn, Sr, Pb, Cr, Al, Co, Cd, Ni, As, Hg and Ba, with Pb exhibiting higher concentrations than allowed limits under French law (Marzocchi, 2016). This poses challenges if *Sargassum* use as a food or food additive is on the portfolio for the Caribbean region.

Table 2: Concentrations of organochlorine pesticides and PCBs detected in the WCR (Fernandez et al., 2007)



Country	Media	Concentrations reported	Source
South American Region			
Venezuela	Tree oyster: *Isognomon alatus*	γ-Chlordane <0.22 to <0.74, α-chlordane: <0.13 to <0.45, *trans*-nonachlor <0.12 – <0.40, *cis*-nonachlor <0.21 to <0.72, oxychlordane <0.25 to <0.83, *o-p*′DDE <0.12 – <0.40, *p-p*′DDE <0.44 to <1.5, *o-p*′DDD <0.13 to <0.43, *p-p*′DDD <0.32 to <1.1, *o-p*′DDT <0.18 to <0.61, *p-p*′DDT 0.52–2.2, total PCBs 0.60–12 (ng/g dw)	Jaffé et al. (1998)
Venezuela	Bivalve: *Tivela mactroidea*	Total hexachlorocyclohexanes ND–0.5, α- and γ-chlordanes ND–0.2, *cis-* and *trans*-nonachlor ND–0.4, dieldrin ND–0.7, heptachlor ND–0.6, endrin ND–trace, total DDTs 0.9–2.3, total PCBs 4.8–63 (ng/g dw)	Jaffé et al. (1995)
Central American Subregion			
Mexico	Bivalve: *Crassostrea virginica*	Lindane 0.45–0.066, DDD 1.28–1.85, endrin ND–56.7, aldrin 5.26–6.56, Aroclor 1254 1.65–2.0 (ng/g dw)	Gold-Bouchot (1993)
	Bivalve: *Rangia cuneata*	Lindane 1.21, DDD 16.8, endrin ND, aldrin ND, Aroclor 1254 3.96 (ng/g dw)	
	Bivalve: *Brachidontes recurvus*	Lindane 1.25, DDD 4.09, endrin ND, aldrin ND, Aroclor 1254 3.96 (ng/g dw)	
	Sediments	Lindane ND–0.57, DDD ND–0.55, DDE ND–17.67, aldrin ND–9.02, HCB ND–0.32, Aroclor 1260 ND–12.99, Aroclor 1254 ND–258.6 (ng/g dw)	
Northern Caribbean Region			
Dominican Republic	Bivalves	Total chlordanes 0.51–7.47, total DDTs BDL–30.9, total PCBs 11.3–82.3 (ng/g dw)	Sbriz et al. (1998)
	Sediments	Total chlordanes BDL–7.47, Total DDTs 0.21–12.5, Total PCBs 0.46–41.9 (ng/g dw)	
Jamaica	Sediments	α-Endosulfan 0.003–1.0, β-endosulfan 0.006–0.76, endosulfan sulfate BDL, *p-p*′DDT 0.03–0.04, dieldrin 0.001, aldrin 0.002–36.7, endrin 0.006, lindane 0.003–0.77, HCB 1.01, diazinon 0.002–0.007 (ng/g)	Mansingh and Wilson (1995)
	Seawater	α-Endosulfan 0.118–5.56, β-endosulfan 0.01–15.7, endosulfan sulfate 0.0003, *p-p*-DDT 7.02, dieldrin 0.014–3.75, aldrin BDL, endrin 0.012–0.9, lindane BDL, HCB BDL, diazanon 0.0003–0.1 (ng/L)	
Jamaica	Sediments	Total chlordanes 0.4–0.92, Total DDTs 1.45–23, dieldrin 0.24–6.13, total PCBs 0.76–73 (μg/kg dw)	Jaffé et al. (2002)

Evidence exists that supports that there are high concentrations of some of these contaminants in the Caribbean. For example, blood levels of mercury in newborns in Bermuda were eight times higher than those in Canada. 85% of that exposure was from methylmercury, indicating that it came from seafood. This was mostly from predator fish suggesting that it was biomagnified up the trophic levels (Dewailly, 2012). This presents a special problem since *Sargassum*, a primary producer, readily absorbs Hg, this exposing aquatic organisms to the bioaccumulated metal. Still more baseline studies are needed to supplement those carried out in Costa Rican and Panamaian coral reefs on the aquatic concentrations of persistent, bioaccumulative and toxic pollutants (PBTs) pollutants in the region. The research in Costa Rica and Panama, which targeted 12 trace metals, identified potential sources and pathways of the pollutants. The culprits included human activities like deforestation, sewage discharges, oil spills, the misuse of fertilizers, and topsoil erosion (Guzman, 1992). There are no recent follow-up studies in the last 30 years, with the exception of studies in other areas (Calicet, 2002). Before recommendations on Sargassum use can be made, more baseline studies are need in the Eastern Caribbean.

References

Bermudez, Y.G., & Rico, I.L.R. (2011). Nickel biosorption using Gracilaria caudata and *Sargassum* muticum. Chemical Engineering Journal: 166, (1), 122-131 https://doi.org/10.1016/j.cej.2010.10.038 .

Botello, A.V. (1991). Pollution by petroleum hydrocarbons in sediments from continental shelf of Tabasco State, Mexico. *Bulletin of Environmental Contamination and Toxicology, 47,* (4). 565-571.

Calicet, M., & Argese, E. (2002). Heavy metal contamination in the seaweeds of the Venice lagoon. *Chemosphere, 47*, (4). 443-454. https://doi.org/10.1016/S0045-6535(01)00292-

Cruz, C.C.V., & Costa, A.C.A.D. (2004). Kinetic modeling and equilibrium studies during cadmium biosorption by dead *Sargassum* sp. Biomass. Bioresource Technology: 91,(3), 249-257. https://doi.org/10.1016/S0960-8524(03)00194-9

Dewailly, E., & Rouja, P. (2012). Evaluation of Public health Intervention to lower mercury exposure from fish consumption in Bermuda. *Volume 10* (10). *PLOS.*

Esmaeli, A., & Saremnia, B. Removal of mercury(II) from aqueous solutions by biosorption on the biomass of *Sargassum* glaucescens and Gracilaria corticata. *Arabian Journal of Chemistry: 8*, (4), 506-511. https://doi.org/10.1016/j.arabjc.2012.01.008

Ferdinand, F., & Boluda, J.C. (2016). Prospective element Analysis of Algae biomass accumulated at the dominican Republic shores during 2015. *Volume 11, Enero-Marzo.*

Fernandez, A., & Singh, A., & Jaffe, R. (2007). A literature review on trace metals and organic compounds of anthropogenic origin in the Wider Caribbean Region. *Marine*

Pollution Board, 54, (11). 1681-1691. https://doi.org/10.1016/j.marpolbul.2007.08.007

Freitas. A.C.S., & Guimarães, JRD. (2016) Strontium-85 bioaccumulation by *Sargassum* spp. (brown seaweed) and *Galaxaura marginata* (calcareous seaweed). *Science of The Total Environment. 75* (1-2). 225-233. https://doi.org/10.1016/0048-9697(88)90035-6

Guzman, H.M., & Jimenez, C.E. (1992). Contamination of coral reefs by heavy metals along the Caribbean coast of Central America (Costa Rica and Panama).*Marine Pollution Bulletin* 24, (11). 554-561. https://doi.org/10.1016/0025-326X(92)90708-E

Marzocchi, M., & Badocco, D. (2016). Metals in Undaria pinnatifida (Harvey) Suringar and *Sargassum* muticum (Yendo) Fensholt edible seaweeds growing around Venice (Italy). *J Applied Phycology. 28* (4). Retrieved from https://doi.org/10.1007/s10811-016-0793-8

Miao, L., & Yan, W., & Zhong, L. et al. (2014). Effect of heavy metals (Cu, Pb, and As) on the ultrastructure of *Sargassum pallidum* in Daya Bay, China. *Environmental Monitoring and Assessment, 186*, (1). 87-95. https://doi.org/10.1007/s10661-013-3358-1

Sargassum: A Resource Guide for theCaribbean. CAST. [PDF]. Retrieved from https://www.onecaribbean.org/wp-content/uploads/*Sargassum*ResourceGuideFinal.pdf

Schaffelke, B. (2002). Particulate organic matter as an alternative nutrient source for tropical Sargassum species Fucales Phaeophyceae. Journal of Phycology, 35, (6). 1150-1157. https://doi.org/10.1046/j.1529-8817.1999.3561150.x

Siung-Chang, A. Environmental Geochemistry and Health (1997) 19: 45. https://doi.org/10.1023/A:1018438119034

Vieira, D.M., & Costa, A.C.A. (2017). Biosorption of lead by the brown seaweed *Sargassum* filipendula - batch and continuous pilot studies. *Electronic Journal of Biotechnology, 10*, (3). http://dx.doi.org/10.4067/S0717-34582007000300004 Retrieved from https://scielo.conicyt.cl/scielo.php?pid=S0717-34582007000300004&script=sci_arttext& tlng=e

Yang, J., & Volesky, B. (1999). Biosorption of uranium on *Sargassum* biomass. *Water Research, 33* (15). https://doi.org/10.1016/S0043-1354(99)00043-3