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Sargassum Management and Uses in the Caribbean: A Review

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Abstract

Sargassum, though commonly called a seaweed, is a macroalgae originating in the mid-Atlantic that affects Caribbean coastlines, generating an environmental, economic, and social crisis as it washes up on shores. This article aims to highlight the complexity of the issue and the need to address it in a multidisciplinary way. To best address this issue, a collaboration between academia, government, industry, and society is needed. To support industry efforts, this article highlights various studied uses for the seaweed, including its use as an ingredient in fertilizers, cosmetics, and as a source for terpenes, which can be used in the creation of various synthetic polymers. In this sense, the sargassum problem could be converted into a source of valuable resources. However, the constant arrival of sargassum to beaches has negatively affected local economies as it can make an area undesirable for tourism. Due to the large scale of the issue, it can be hard to mitigate. In the Dominican Republic and Mexico, for example, the governments developed monitoring systems to help prepare early responses to the problem. This paper aims to present an initial framework that can be used in future research when addressing the issue of Sargassum in the Caribbean, broadly covering most of the problems it causes, government and non-government management solutions, and possible uses that are being developed for how to deal with it.

Keywords
Sargassum Management, Review, Environmental Challenges

1. Introduction

Sargassum seaweed is a complex environmental issue that requires a multidisciplinary response in order to fully address. More in-depth studies regarding the origin, life cycle, and effects on coastal ecosystems is still needed to understand the extent of the problem. In response, various governments have developed programs for early detection of incoming seaweed clusters to provide early and accurate information to allow for effective decision-making. In this sense, the challenge comes to the integration of scientific knowledge, technological abilities, and environmental needs in order to address this international issue. In Mexico, a collaborative multi-sector effort is expected to achieve commercialization by the end of 2024 (Peters, et al., 2023).

Sargassum is currently a heavily discussed topic in regard to Caribbean beaches. As the seaweed's growth has become unrestrained due to climate change, as ocean temperatures rise and other meteorological and oceanographic changes have created very favorable conditions to foster the sargassum's growth (Secretaría de Marina, 2016). Based on the findings by the Gulf of Mexico Research Consortium (CIGoM), most of the algae affecting the Caribbean comes from clumps that branch off the Sargasso Sea, a region of the Atlantic Ocean to the west of Bermuda, with an approximate area of over 4 million km^2, where the algae float en masse on the surface. Just like Sargassum is not actually a seaweed, the Sargasso Sea is not actually a se. it is a region of the ocean enclosed by the North Atlantic Current, the Canary Current, the North Atlantic Equatorial Current, and the Gulf Stream, which form a closed clockwise loop which encloses the area. This ocean gyre has also been found to recently be in a weakened state, which further contributes to the release of algae clusters (Smeed, et al., 2018).

According to an article by Melendez (2021), the current excess in Sargassum arrivals started being noticed in Spring 2011, slowly increasing until it started becoming an almost unmanageable issue. While the presence of the algae is normal – indeed it was even reported to have been encountered by Columbus himself in his travels – the amount which escapes the Sargasso Sea is not. The macroalgae's reproduction cycle has been accelerated by an increase in organic residues and increased temperature, and the natural ocean and wind currents that would normally constrain it within its native region have also weakened in recent years.

1.1 Objectives

This research work aims not to eliminate Sargassum, but to seek a way in which it can be harvested from the coasts and used for fruitful methods, including as fertilizer, a source of terpenes, an antioxidant, or in pigment manufacturing (Skladal Méndez, 2020), (Silva, Bahcevandziev, & Pereira, 2019). As such, the main objective of this work is to demonstrate the possible usefulness of the Sargassum algae as an opportunity and convince national and international organisms of this. As part of this, the secondary objective is to show the applicability of the Sargassum for industrial and agricultural uses.

Altogether, this work is an initial step in a larger effort to find industrial uses to the masses of Sargassum seaweed that washes up in the Dominican Republic as part of a larger national effort to solve this problem and recoup the significant economic losses that come associated with it. Finally, while the words seaweed and algae will be used interchangeably throughout this work, it is important to note that the Sargassum seaweed is a macroalgae and it is only being referred to as a seaweed as it is what it is called colloquially.

2. A Brief Meta-Analysis

Based on a search on the Scopus database, there have been 6,085 articles published on the general topic of Sargassum since 2020 as of the time of writing this. Table 1 below describes the distribution of the top 10 subject of these articles according to the database. As there is overlap between the categories, however, the total percentage does not add up to 100%. Still, the journals with the most publications are the *Journal of Applied Phycology*, *Marine Drugs*, and the *International Journal of Biological Macromolecules*.

Table 1. Top 10 subject areas for Sargassum research

Subject Area	**Number of Articles**	**Percentage**
Agriculture and Biology	2,878	47.3%
Environmental Science	1,539	25.3%
Biochemistry	1,043	17.1%
Earth Sciences	788	12.9%
Chemistry	738	12.1%
Pharmacology	731	12.0%
Chemical Engineering	549	9.02%
Medicine	531	8.72%
Engineering	506	8.32%
Energy	351	5.77%

Additionally, while our findings as described in the rest of this article show that Sargassum is an ecological issue in the Western Atlantic, most of the research publications come from countries in the Western Pacific instead. Table 2 below shows the number of articles from the top 5 countries publishing research. Regardless, our focus is on the issues it brings to the Western Atlantic and the potential uses, which does limit the number of relevant articles from this list for environmental and economic impacts, but can provide much information on possible uses and general biological information.

Table 2. Top 5 countries by number of publications

Country	Number of Articles
China	1,142
India	738
South Korea	598
Indonesia	470
United States	465

3. Characteristics of the Sargassum: What are we dealing with?

Sargassum is a genus of brown macroalgae in the *Fucales* order, which along with 25 other genera forms the *Sargassaceae* family. The family contains over 550 species globally, over 80% of which fall under the *Sargassum* genus (Mattio, Payri, & Stiger-Pouvreau, 2008). Floating clusters of this algae represent very particular ecosystems in oceans across the world, covering stretches that can be measured in square miles on the surface (Brooks, et al., 2018). Its yearly distribution pattern is affected by thermal, oceanic and meteorologic paterns, where it seems to move through a cycle that both begins and ends in the Sargasso Sea. Besides a large variety of algae species in the clusters, there is also a large amount of macrofauna that subsist along with them, mostly crustaceans (Muñoz Bautista, 2013). In this sense, despite the large issues that arise by the seaweed in shores, it serves as an important ecosystem for many species in marine environments. The geographic location of the Sargasso Sea, where most Sargassum in the Atlantic is located, is shown in Figure 1.

In terms of morphology, the Sargassum genus is one of the most anatomically complex among brown algae which make it very adaptable against spatial and environmental changes (Andrade-Sorcia, et al., 2014). These include structures such as receptacles and aerocysts, the latter of which being what helps the Sargassum not only float, but also perform photosynthesis (Hernández-Garibay, et al., 2006). These morphological aspects make the Sargassum very hardy and widespread. Sargassum algae, while most highly concentrated in the northern Atlantic, can be found floating as far as Japan and New Zealand (Hinojosa, et al., 2010). Additionally, while lower salinity levels can hinder temporarily hinder its growth, this only happens at the early stages of its life (Steen, 2007). However, as salinity seems to be increasing in the Atlantic, there is no sign that its growth could be hampered in the near future (Skliris, et al., 2014)

While many sources attribute the recent blooms to global warming and changing tides, however, other sources indicate that a large part of the new population increase can also be attributed to many other sources. Louime *et al.* cite a reduction of hurricanes in their reproductive region, which has allowed them to grow mostly unhindered. Additionally, an increased nutrient discharge from the Mississippi has fostered growth in the Gulf of Mexico (Smetacek & Zingone, 2013). The same issues are caused by nutrient-rich Sahara dust (Moanga, 2015), as well as biomass discharge from the Amazon River caused by deforestation (Gaskill, 2015). In truth, it is likely a combination of all these and more factors that have caused it to grow and become a global scale issue.

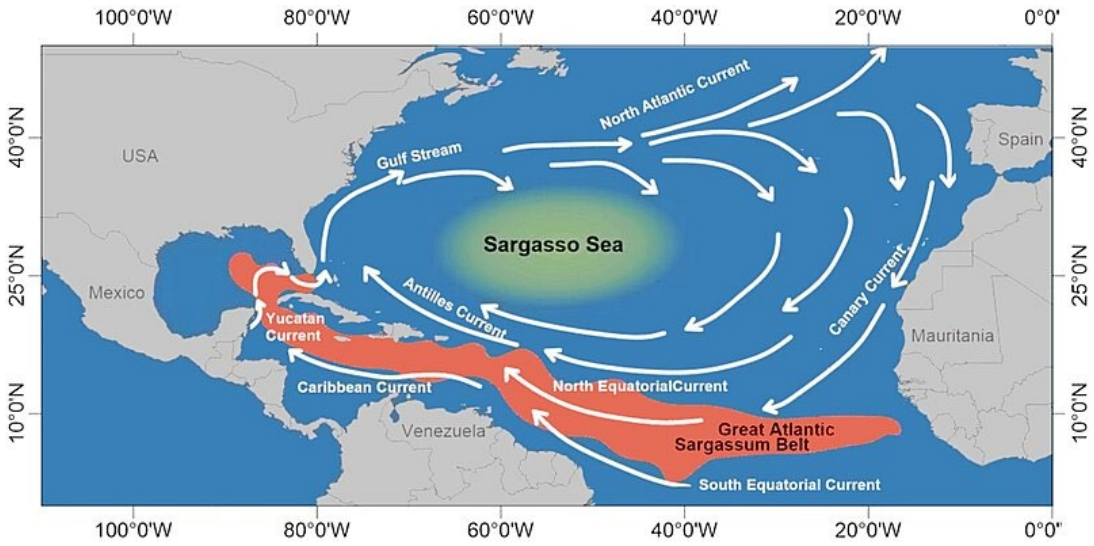

Figure 1. Sargasso Sea (Lopez Miranda, et al., 2021)

4. The Problems caused by Sargassum: What do we need to fix?

Other than the clear harm that Sargassum does to the tourism industry as it makes beaches less appealing, the massive level at which it is now washing up is bringing new environmental, health, and economic problems. Firstly, as washed-up Sargassum rots, it releases hydrogen sulfide, which apart from the rotten egg-like smell, can cause nausea and headaches after prolonged exposure (Doyle & Franks, 2015).

Additionally, while Sargassum does play part of the ecosystem as a source of nutrients in small amounts, it releases Arsenic and other potentially toxic metals, which can negatively affect coastal ecosystems (Olguin-Maciel, et al., 2022). In terms of faunal damage, at least 78 different species in the Mexican coast die due to the high levels of ammonium and hydrogen sulfide from decaying Sargassum, deteriorating the water quality as far as 480 m from the shore (Rodríguez-Martínez, et al., 2019). On top of this, the large, dense algae clumps block out sunlight from the ocean floor, preventing coral reef species from performing photosynthesis, and reduce oxygen in near-shore waters. This results in an increased mortality of near-shore seagrasses which are vital to fauna and corals. In the long-term, it can cause eutrophication of coastal waters, which can bring more issues into the mix (Van Tussenbroek, et al., 2017).

Outside of environmental concerns, sargassum can clog boat engine intakes and rudders (Doyle & Franks, 2015), it has had clear impacts on the tourism industry all over the Caribbean. A study on the Turks and Caicos Islands has shown that the brown algae has had negative impacts both on local food sources, as much of the local diet and hotel meals depend on local seafood, as well as tourism activities. As beaches become less attractive, more tourists are preferring inland activities, and hotels have had to employ additional resources to remove the seaweed from the shore as well as pick up as much nearby floating sargassum as possible since it also negatively affected water sports equipment (Bartlett & Elmer, 2021).

According to a study by Rosellón-Druker, et al. (2023), residents of Quintana Roo, Mexico, and Florida indicated that while Sargassum did regularly wash up on shores, it wasn't until 2011 that it started being an issue with the massive inundations that are common nowadays. While some people see it as a positive thing (about 40% of Floridians according to the study) for its possible benefits as a nursery habitat for marine species, it is still mostly seen as a negative issue. In Quintana Roo, specifically, 80% of respondents saw it as a problem that harshly impacted fisheries and tourism. Another similar study by Fraga and Robledo (2022) focused on the combined impact of the Sargassum arrivals along with the COVID-19 pandemic in the Mexican Caribbean. Their study found that the March to June 2020 lockdowns in Mexico was the "most severe economic paralysis of its short history as a tourist destination," with over 100,000 jobs lost and a 98% reduction in tourism activities. On top of this, the Sargassum had been arriving *en masse* to the Riviera Maya region, with over a million metric tons reported in 2018 and 2019, blocking the white sands and turquoise waters underneath them.

The growing concern of the Sargassum invasion has been studied almost as long as it has been ongoing. Some of the previously cited studies have reported 2011 as the first large algae arrivals, with some subsequent peaks in 2015 and 2018 in Florida and Mexico. However, reports in the Caribbean were consistently increasing every year, with most reports being made on the first half of the year (Oficina Nacional de Estadistica, 2023). In a 2023 interview with the Dominican Minister of the Environment, it was indicated that an expected three million tons of seaweed would arrive in the island nation over the course of the year, although it was unclear how the number was determined (Listín Diario, 2023).

5. Management, Control, and Monitoring Programs: What are we doing about it?

Many countries around the Caribbean have worked, either jointly or individually, to create Sargassum monitoring systems to help predict and prepare for the incoming waves of seaweed. In 2023, the Dominican Republic created the *Mesa Multisectorial para la Gestión Integral del Sargazo* (Multisector Table for Integral Sargassum Management), which aims to manage arrival of pelagic Sargassum for the purpose of mitigating ecological, touristic, economic, and human health impacts and led by the Ministry of the environment (del Cid, 2023). In 2021, a collaborative panel was held between Mexico and the Dominican Republic with support from the UN Food and Agricultural Organization (FAO), where researchers and industry representatives joined to share experiences and discuss solutions. Most importantly, scientistsfrom the CICIMAR center (Mexico) shared their diagnostic and predictive models in order to create a larger-scale system to predict arrival times and sizes for Sargassum (FAO, 2021).

The efforts to create monitoring and tracking systems have been successful so far. The University of South Florida's Optical Oceanographic Laboratory, for example, has developed a satellite-based sargassum watch system based on satellite images to detect and predict pelagic Sargassum masses (Trinanes, et al., 2023). The United States has also set up a Sargassum tracker in the Caribbean Coastal Ocean Observing System (CARICOOS, 2024). Mexico's UNAM has, on their side, their national earth observation lab (LANOT). Here, a Sargassum Monitoring proyect has created algorithms to detect Sargassum blooms around the Quintana Roo region based on satellite images from the EU's COPERNICUS system and using oceanic current data from the Hybris Coordinate Ocean Model consortium (LANOT, 2021). In addition, many studies have been focusing on creating and improving methods for identifying Sargassum in near real-time based on satellite imaging (Marechal, Hellio, & Hu, 2017), (Putman, et al., 2020).

Management programs, however, are where the challenge lies. Some programs attempt to trap and capture the free-floating blooms before they arrive to shore (AlgeaNova, 2024), but this process is costly and inefficient due to the requirement for specialized ships, the vastness of the ocean, and the excessive amounts that arrive to shores, not to mention the length of floating barriers required even for small-scale implementations. In Mexico, for Example, it was reported that 30 ships collected over 44 thousand tons of Sargassum over the 2021 season (Secretaría de Marina, 2021). Additionally, there is a list of recommended practices from the EPA which includes removing sand and trapped wildlife from the collected algae, which can make the process more difficult for large-scale implementations (EPA, 2023).

The more common solution is to collect the washed-up seaweed after it has landed on the shores, and ideally before it starts to rot and release unpleasant odors, which starts after about three days. Estimations indicate that one kilometer of shoreline can cost up to 1.5 million dollars to clean up between workforce, machinery, and disposal, on top of the regular beach maintenance costs that hotels incur (Acosta Guzman, 2023). In addition, a 2023 economic study by the University of Florida indicates that aside from beach cleanup, Sargassum composting is also a fairly expensive endeavor, with an expected annual cost of US$387,000 for a city like Ft. Lauderdale, FL (Blare, et al., 2023). In 2023, the Dominican government has invested over a million dollars in equipment dedicated to cleaning up public beaches, with a promise to invest an additional million, and a call to other regional governments to work together to solve the problem (Presidencia de la República Dominicana, 2023).

6. Studied Uses: What do we do with the Sargassum?

Despite all the problems it causes, there are many potential uses for Sargassum which could be economically viable, after further studies. The EPA (2023) claims that proposed uses for the algae include Compost and fertilizer, biosorbent, bioplastics, biochar/charcoal briquettes, adobe bricks, cement additive, chipboard, livestock and fish food, biofuels, nanomaterials, soap, pharmaceuticals, and food supplements. In addition to these, Lopez-Gonzalez, et al. (2023) have identified other uses including analgesics, antioxidants, lotions and cosmetics, paper and textiles, resin,

and asphalt. This section purports to find which of these uses have been studied, which could be commercially or industrially viable, and which would be recommended for immediate implementation to manage the tons of algae washing up on Caribbean shores.

Beginning with fertilizer and animal feed, studies into Lead, Chromium, Nickel, Copper, Cadmium, and Zinc levels in Sargassum have been measured as part of preliminary studies into the viability of *Sargassum natans* and *Sargassum fluitans* species which wash up in the Dominican Republic. The study concluded that while the metals were detected, they were within acceptable levels, indicating their viability for fertilizer and animal feed use (Tejada-Tejada, et al., 2021). Being plant matter, Sargassum is already fairly easy to integrate into animal feed. A 2020 study shows no adverse effects and strong nutritional benefits in the integration of Sargassum as up to 10% of ruminant feed ingredients (Choi, et al., 2020). As fertilizer, it has been found that Sargassum can improve organic matter content, soil structure, and moisture storage, although it is recommended to remove excess salt before usage (Roberts, et al., 2015). In addition, algae components in fertilizer have been shown to improve nutrient absorbtion, fruit yield, and protection against pests and diseases (Louime, et al., 2017).

As fuel, Sargassum-based biocharcoal has been found to have better potantial as solid fuel than low-ranked coals (Farobie, et al., 2022). For bio-fuel production, it has been found that Sargassum can have a liquefaction yield of up to 7.2%, with no sulfur and low nitrogen, which means it could be upgraded to a biofuel with relatively low heath impacts upon usage (Rahbari, et al., 2019). This upgrade can be achieved by co-pyrolisis of the Sargassum bio-oil with polystyrene, which improved the heating value and further reduces nitrogen content (Kositkanawuth, et al., 2017). A 2020 case study in Barbados shows that Sargassum biomass can be converted into biomethane, with the remaining digestate can be used as fertilizer, becoming effectively a two-pronged solution to mitigate the costs associated with Sargassum collection (Thompson, Young, & Baroutian, 2020).

In the field of cosmetics, Sargassum-derived products have been found to be particularly effective for anti-inflammatory, skin-whitening (Shanura Fernando, et al., 2018), anti-oxidant, and anti-wrinkle (Mansauda, et al., 2018). Additionally, Sargassum extract can be used as a natural preservative in sunscreen (Sipahutar, et al., 2019), as a base for lip balm (Abdullah, et al., 2018), and has the potential of being applicable in other cosmetics for similar purposes. While we have not found any cosmetics forsale which specifically list Sargassum as an ingredient, there are many which do feature seaweed and/or algae extracts in their composition.

In textiles, Sargassum fabrics boast a good ability to keep warm, air permeatibility, low weight, and biodegradability (Liu, et al. 2022). Additionally, it is also possible to create fabric dye from Sargassum, although it does not seem that this dye has any special properties as far as we could find (Ab Kadir, 2021). Finally, startups like the Sargasse Project are working to turn the algae masses into paper (Sargasse Project, 2023).

In more advanced applications, Sargassum can be a source material for extracting nanoparticles of zinc oxide (Bai, et al., 2023), gold and silver (Gonzales-Ballesteros, et al., 2020), Palladium (Kamaraj, et al., 2023), and copper oxide (Rajeshkumar, et al., 2021). These particles can be used in a variety of applications including disinfectants, insecticidals, dye degradation, as well as many other biological and environmental applications.

7. Conclusions

The findings of this work provide an uplifting vision for the issues brought by the Sargassum algae across the Caribbean and other affected regions, presenting concrete opportunities to transform this environmental challenge into valuable sources of energy and sustainable products. The discoveries we present highlight diverse and promising applications of the Sargassum, such as methane production, more environmentally friendly fuel sources including coal and biogas, and synthesis into fertilizers.

An innovative focus can consider not only the health and economic impacts that hit Caribbean nations, but also focus on the potential capacity of transforming the source of the problem into eco-friendly and economically viable products that can offset the costs of cleaning it off the shores. Multi-national initiatives have been initiated in order to share resources and technologies and more easily mitigate many of the problems while trying to preserve the vital ecosystems that also need the Sargassum seaweed in order to subsist.

This work represents an initial step into a larger national project promoted by the Dominican government in order to address the ever-growing influx of Sargassum into Caribbean shores. Future work will focus on more specific case

studies in regard to environmental, economic, and social implications from the large-scale implementation of collection and processing technologies. This will mean exploring the scalability and replicability of implemented techniques and technologies in other affected regions across the globe. This includes continuous development of more efficient and sustainable technologies for the same purposes. These efforts will contribute not only to mitigating the damages from the algae, but also open new opportunities for sustainable resource management, aligning itself with the goals of reducing climate change and promoting environmentally responsible practices.

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