

# Sargassum Invasion of Coastal Environments: A Growing Concern

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**Abstract:** Floating tropical brown macroalgae, commonly called *Sargassum*, besieging the Caribbean coastlines have long been a regular occurrence in the region, especially during the fall and winter months. These washed-up seaweeds are considered by scientists as an important part of the coastal ecosystem, as they serve as habitat and nurseries for numerous marine species. However, in recent years, the region has seen an explosion in *Sargassum* densities with unusually high extent and frequency. This natural catastrophe, as some label the 2013 invasion, has even crossed the Atlantic Ocean to reach the west coast of Africa. Some scientists have linked this disaster with global climate change and the concomitant higher than normal temperatures. Now the question is being raised as to whether the latest seen invasion of *Sargassum* represents a seasonal anomaly or a regime shift in ocean currents and climate. Therefore, it is urgent for the scientific community to understand the causes of these recent occurrences and provide potential remedial solutions, as these invasions could have significant negative impacts on marine ecosystems, even disrupting entire economic activities of local communities.

**Keywords:** *Sargassum*, Climate Change, Marine Ecosystems, Algae, Bioenergy

## Introduction

### Origin of the Sargassum

Periodically, mats of brown algae drift along the coastlines of most Caribbean island nations. This phenomenon happens basically every winter, when trade winds are usually strong in the region, driving great amount of drifts to the coast (Gavio *et al.*, 2015). These algae are of two species, namely *Sargassum fluitans* and *Sargassum natans* (Fig. 1) (Moreira and Alfonso, 2013). These are pelagic algae that grow in the open sea without a sound clip. Usually a strong presence of these algae is noticed in the region called the Sargasso Sea (Sargazzo the Italian word for seaweed). The Sargasso Sea has always been considered as the principal source of these golden tides of pelagic *Sargassum*. This is a region in the North Atlantic Ocean, between the meridians 70° and 40° W and the parallels 25° and 35° N (Laffoley, 2011). It is the only sea without a shoreline. Its boundaries are formed by the North Atlantic Drift to the north, the Gulf Stream to the west, the Canary Current to the east and north equatorial current in the south (Fig. 2)

(Laffoley, 2011). Its total area-although variable - is 3,500,000 square kilometers (Laffoley, 2011). This region is characterized by the frequent absence of wind currents on the one hand and the abundance of plankton on the other (Laffoley, 2011). The waters in this space operate in a slow circular motion and all floating objects drift between these limits (Laffoley, 2011).

Over the past few decades, the volume of these floating algae that washed-up along the Caribbean coastlines has been increasing (Johnson *et al.*, 2013). A huge *Sargassum* increase documented by Smetacek and Zingone (2013) in the Gulf of Mexico in the 90s, was traced back to higher nutrient loads discharged into the Mississippi river. In another study conducted by Gower and King (2011), such an unprecedented amount of seaweed was surveyed in the Gulf of Mexico, that it prompted regulators to label 2005 as the “*Sargassum* Year”. This study, published in 2013, revealed that the huge amount of brown tides seen in the Gulf in 2005 and 2011 actually originated from there and not from the Sargasso Sea as previously thought (Gower *et al.*, 2013). An estimated 1 million tons of algal biomass are

transported from the gulf to the Sargasso Sea every spring. By 2011, *Sargassum* biomass drifts in the Caribbean region reached a peak, by recording a 200-fold higher biomass than the previous eight years. That was also the first time in recent memory, that washed-up *Sargassum* reached the coast of Africa (Smetacek and Zingone, 2013). Johnson *et al.* (2013) reported unprecedented amounts of pelagic seaweed were washed ashore along the Western coastline of Africa (Fig. 3).

#### Underlying Causes of the Sargassum Invasion

Several hypotheses have been put forward, trying to address this question. According to several sources, global climate change might have forced the Sargasso Sea to move further south, bringing the seaweeds closer to the Caribbean Sea (Valesco, 2015; Sargeant, 2015). Some others linked the *Sargassum* invasion to the lack of cyclones in the region during the last decade (<http://coastalcare.org/sections/inform/page/4/>). This seems to create optimal conditions for the growth of algae. In addition, the deviation of the Gulf Stream to the south promotes an influx of algae in the Caribbean (<http://ambergriscaye.com/forum/ubbthreads.php/topics/506881/the-journey-of-the-sargassum.html>). A third school of thought considers the increased intake of nutrient-rich Sahara dust (including Fe, K and phosphate) as one of the major drivers facilitating the growth of algae in the sea (Moanga, 2015). The fourth

hypothesis attributes the *Sargassum* invasion to nutrient overload resulting from deforestation of the Amazon basin in Brazil (<http://www.newsweek.com/2015/07/10/sargassum-ruining-beaches-texas-tobago-347735.html>). In fact, because of deforestation, the amazon river spooft tons of organic matter and nutrients to the sea thus promoting excessive growth of algae. They advanced the hypothesis of high flow of nutrients from South America's Amazon and Orinoco Rivers mixing with warmer ocean temperatures as the basis for this harmful algal bloom (<http://www.newsweek.com/2015/07/10/sargassum-ruining-beaches-texas-tobago-347735.html>).

The scientific community does not subscribe unanimously to all these assumptions. However, nutrient discharge from the Amazon river seems to be the most plausible cause. In fact, new studies have shown the formation of a small 'Sargasso Sea' in eastern Brazil with an algae tail dragging all the way to the West-Indies (Gower and King, 2008). e.g., Jim Gower and Stephanie King of Institute of Ocean Sciences (IOS) in their 2008 publication entitled "Satellite Images Show the Movement of Floating *Sargassum* in the Gulf of Mexico and Atlantic Ocean" used satellite imagery to present the first mapping of the full distribution and movement of the population of *Sargassum* in the Gulf of Mexico and western Atlantic in the years 2002 to 2008 (Gower and King, 2008).

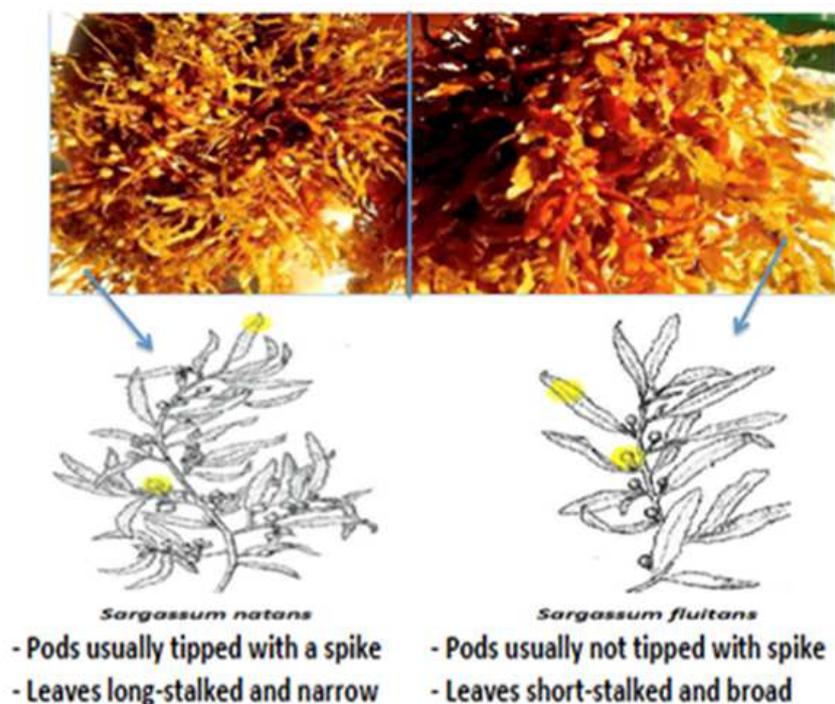


Fig. 1. *Sargassum fluitans* (left) and *Sargassum natans* (right) – Sources: Morphology of *Sargassum fluitans* and de *S. natans* (Doyle and Franks, 2015; Le Lann, 2009)



Fig. 2. <http://wwz.ifremer.fr/guyane/content/download/41806/569470/file/Sargasses%20Guyane.pdf>

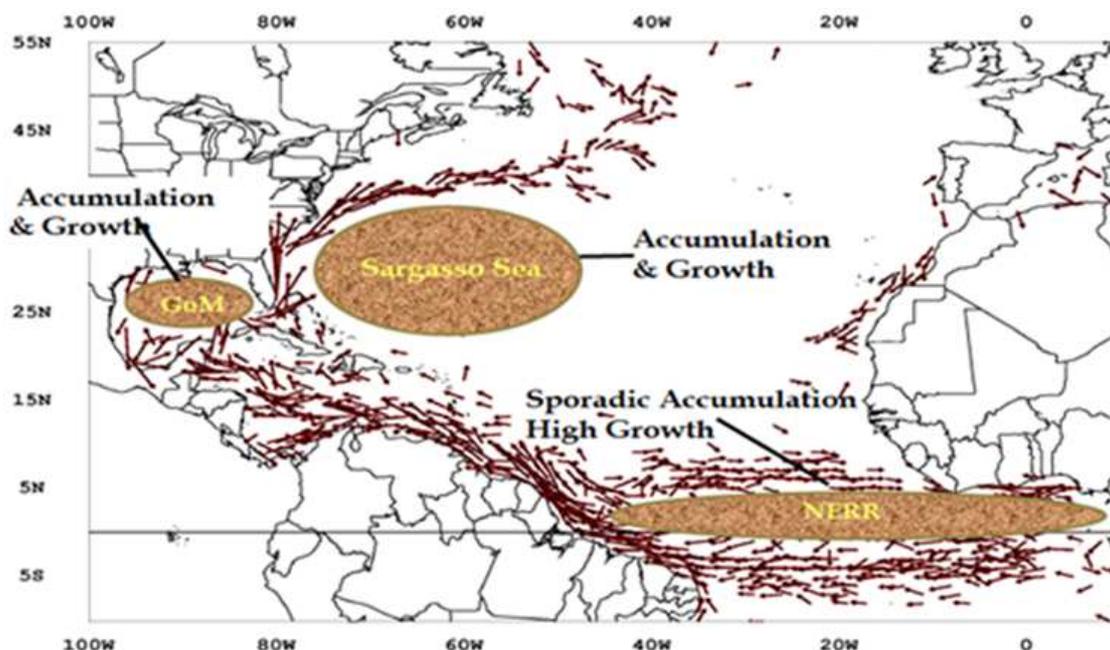


Fig. 3. Growth and Accumulation of *Sargassum* in the region – Sources: The regions of accumulation and algae growth in the Atlantic Ocean (Derilus *et al.*, 2014; Johnson *et al.*, 2013)

### Potential Impacts of the *Sargassum* Invasion

Significant economic, environmental and health impacts have been attributed to the *Sargassum* invasion in the region. These severe influxes are "harmful algal blooms" that can lead to fish kills, beach fouling, tourism losses and even coastal dead zones (Lopez *et al.*, 2009). The tourism industry, on which the region depends heavily, has taken a serious hit (Defenders of Wildlife, 2010). The foul smell generated by decomposing *Sargassum*, along with the

proliferating biting sand fleas, have forced tourists to stay away from these usually pristine waters ([http://www.dailymail.co.uk/travel/travel\\_news/article-3315178/EARTHPRINTS-Transformation-Mexican-vacation-hotspot-comes-price.html](http://www.dailymail.co.uk/travel/travel_news/article-3315178/EARTHPRINTS-Transformation-Mexican-vacation-hotspot-comes-price.html)). From Barbados to the Dominican Republic and Mexico, all countries affected by the *Sargassum* invasion are experiencing unforeseen cancellations during the heavy tourist season (<http://www.theguardian.com/environment/2015/aug/10/caribbean-bound-tourists-cancel-holidays-due-to-foul->

smelling-seaweed). Not only they are losing revenues due to the invasion, but also it costs them money to clean these beaches (<http://www.theguardian.com/environment/2015/aug/10/caribbean-bound-tourists-cancel-holidays-due-to-foul-smelling-seaweed>). From the Dominican Republic in the north, to Barbados in the east and Mexico's Caribbean resorts to the west, officials have authorized emergency money to fund cleanup efforts and clear stinking mounds of seaweed that in some cases have piled up nearly 10 feet high on beaches, choked scenic coves and cut off moored boats (<http://www.theguardian.com/environment/2015/aug/10/caribbean-bound-tourists-cancel-holidays-due-to-foul-smelling-seaweed>). In Cancun, Mexico alone, the authorities estimate that the cleaning of each meter of coastline could range as high as a \$1000.00. They have budgeted almost \$10 million and hired approximately 5000 temporary workers to remove the seaweed that engulfed the Caribbean coast of Mexico (Hoang *et al.*, 2016). The island of Tobago has even declared a state of natural disaster (<http://ambergriscaye.com/forum/ubbthreads.php/topics/506881/the-journey-of-the-sargassum.html>). Some officials are calling for an emergency meeting of the 15-nation Caribbean Community, worried that the worsening seaweed influx could become a chronic dilemma for the globe's most tourism-dependent region (<http://ambergriscaye.com/forum/ubbthreads.php/topics/506881/the-journey-of-the-sargassum.html>).

When it comes to public health, although these algae are either venomous nor allergenic, it is not advisable to bathe in beaches with high concentrations of algae. There is at this stage an elevated risk of drowning (<http://www.nytimes.com/2011/10/16/travel/caribbean-beaches-dig-out-from-massive-seaweed-invasion.html>). The presence of rafts of algae in the sea can also be havens for some marine species that can cause irritation upon contact (<http://ambergriscaye.com/forum/ubbthreads.php/topics/506881/the-journey-of-the-sargassum.html>). In addition, under certain climatic conditions, the decomposition of algae on the beaches causes the release of Hydrogen Sulfide ( $H_2S$ ) gas, responsible also for the foul odor of "rotten eggs" (Oyesiku and Egunyomi, 2014). Hydrogen sulfide is in fact a toxic gas, however its level of toxicity is a function of the inhaled dose and the duration of exposure.  $H_2S$  is likely to cause, even at low doses, irritation of the eyes and respiratory tract. Therefore, people suffering from respiratory diseases (respiratory failure, asthma, chronic bronchitis, etc.) must avoid areas of stranded algae in a state of decomposition.  $H_2S$  is detectable at a concentration of 0.05 ppm, it can serve as a warning signal. But when the concentration reaches the threshold of 50 to 150 ppm, it paralyzes the olfactory nerve and at 300 ppm we lose consciousness. The maximum acceptable threshold in a medium is 10 ppm and a concentration of 50 ppm

require immediate evacuation. Although the collection of fresh algae is harmless, the collection of rotting algae should be treated more cautiously by professionals equipped with masks to protect against  $H_2S$  gases (Agence Régionale de Santé Martinique, 2011). In other jurisdictions, including France and China,  $H_2S$  produced by decomposing algae on beaches have killed both humans and farm animals (Oyesiku and Egunyomi, 2014; Revue de presse «Caraïbes» (2015)).

### *On the Environmental Front*

The presence of *Sargassum* in water can be very useful for certain species, as it provides food and shelter for some marine species (lionfish, young sea turtles, tuna, kingfish) (Lopez *et al.*, 2008). As stated in the Defenders of Wildlife in 2010 "Sargassum is also a vital nursery for newly fledged sea turtles that are especially vulnerable to ocean-going predators" (Defenders of Wildlife, 2010). Under certain conditions, the presence of algae on the beaches can help fight beach erosion (Bruun, 1983). This was demonstrated in Bruun 1983, where beach stability was heavily affected upon removal of invading *Sargassum* (Bruun, 1983). But, at high concentrations, *Sargassum* may negatively affect marine flora and fauna located near the coast. The accumulation of algae on the water surface prevents light penetration (Lopez *et al.*, 2008). Therefore, seagrasses and corals are affected by the lack of light necessary for photosynthesis (Lopez *et al.*, 2008). On the beaches, algae disturb nesting sea turtles and make it difficult, if not impossible, for the movement of baby turtles from the shore to open water (Lopez *et al.*, 2008; Bruun, 1983). The massive *Sargassum* beaching is becoming a major source of harm to coastal environments. Cleanup efforts by work crews may also worsen beach erosion. In addition, the decomposition of algae may lead to the alteration of water chemistry which subsequently causes the death of certain fish species susceptible to falling oxygen levels (Hoang *et al.*, 2016).

### *How can we turn this Problem into Opportunities?*

In terms of energy value, *Sargassum* like any other type of biomass represent attractive opportunities (Gervais and Marty, 2014). *Sargassum* can be converted to biogas via anaerobic digestion. Biogas made predominantly of methane, has a high-energy value, that can be used to meet many of our energy needs (Gervais and Marty, 2014).

The feasibility of this process is currently being tested in the CRES laboratory at the University of Puerto Rico Rio Piedras (CRES-Center for Renewable Energy and Sustainability). Experiments have shown that for every Kg of total dried solids of algae fed to a bioreactor, a biogas (mixture of methane and carbon dioxide, etc ...: Energy sources) equivalent of 50 L was generated, whose composition in methane is greater

than 55%, with an excellent CH<sub>4</sub>/CO<sub>2</sub> ration of 2:1 (De La Rosa-Acosta *et al.*, 2015). These studies were conducted in two 15L bioreactors at different salinities (10 and 35 ppt seawater). Biogas production yield, in the 10 ppt was higher than in the 35 ppt due to the presence of two inhibitors (sodium and sulfur) of methanogenic organisms present in the 35 ppt seawater (Fortuné *et al.*, 2015). The 35 ppt bioreactor produced 67 mL b/g per gTS\*d which is 67 liters of biogas per kg TS/d. The 10 ppt bioreactor produced 83 ml b/g per gTS\*d which is the same as 83 L b/g per gTS\*d (Fortuné *et al.*, 2015). Indeed, it has been demonstrated that it is possible to produce biogas from *Sargassum* using seawater, which is abundantly available taking thereby pressure off limited fresh water resources (Gervais, 2014). Since fresh water has a cost for washing the seaweed prior to use and also in the preparation of bioreactor feedstock, the use of sea water seems to be an attractive option for the production of biogas in island jurisdictions such as Puerto Rico where we face limitations on freshwater supplies. But we must consider the choice of materials for the manufacture of digesters due to salt corrosion.

*Sargassum* displayed tremendous benefits as soil amendment (McHugh, 2003). When used as an organic nutrient-rich fertilizer (Fig. 4), *Sargassum* appeared to increase not only crop yield, but also soil characteristics (McHugh, 2003). In a study conducted at the University of Puerto Rico CRES laboratory, after transformation into biogas in an anaerobic system, the effluents from the bioreactors were tested and proven to be excellent sources of nutrients. Results from these studies revealed, that even considering the low NPK content of the effluents, (N: 6.3 mg/100 g; P: 96.5 mg/100 g and K: 28 mg/100 g), *Sargassum* outperformed inorganic fertilizer and therefore was recommended as fertilizer (McHugh, 2003). From these findings, it can be concluded that a high percentage of NPK does not necessarily mean better fertilizer. The total NPK of *Sargassum* although generally lower compared to conventional fertilizers, seems to be assimilated by plants more effectively as slow release nutrients. In addition, as previously demonstrated (Kumari *et al.*, 2013; Roberts *et al.*, 2015), organic fertilizers seem to increase the organic matter content, the soil structure and moisture storage capabilities of soils. Finally, it is recommended that the excess salt in *Sargassum* be removed before use for agricultural purposes in order to avoid soil salinization and groundwater pollution. The mouths of rivers e.g., can be used to remove excess salt from algae by simply washing the harvested algae prior to processing as fertilizer production. The exposure of algae to rain after collection next to the beach will also remove some of the existing salt. Some advantages of *Sargassum* as organic fertilizers are listed below (McHugh, 2003).



Fig. 4. Production of organic fertilizer from *Sargassum* (By Georges Valme, Leogane Haiti)

Algae extracts and algae have been shown to:

- Improve water holding capacity
- Promote the growth of beneficial soil microbes
- Promote root growth and development
- Improve the absorption of nutrients through the roots
- Increase fruit yield
- Promote rooting cuttings
- Encourage abiotic stress tolerance in plants
- Improve protection against pests and diseases (nematodes, fungal and bacterial pathogens)

Furthermore, *Sargassum* can be ground into a more or less fine powder and mixed in proportion of 15 to 20% with other carbon sources (biomass) to produce charcoal briquettes (Gervais and Marty, 2014). In many countries, trees are being harvested on a large scale in the processing of cooking charcoal, leading to massive deforestation. Processing the *Sargassum* into briquettes will provide an attractive and economically viable alternative to charcoal production from wood.

## Conclusion

The *Sargassum* invasion of Caribbean, African and the Gulf of Mexico beaches is a recent phenomenon that is most likely due to the impact of human activities on marine ecosystems. Global Climate Change and the concomitant higher than normal temperatures are currently being looked at as the main driver. There is

yet no scientific consensus on the origins of this problem and how to address the specific causes with the goal of redressing this natural catastrophe. In the meantime, the accumulation of these algae on beaches continues to have a tremendous impact on tourism in the region, as well as on the balance of the marine ecosystems and even on the health of affected local populations. However, this unprecedented invasion seems to offer several economic opportunities in the energy and agricultural sector. This macroalgae can in fact be transformed into biogas and biocoal as an energy source or organic fertilizer for plant health and soil amendment. Ultimately, these newly discovered characteristics of *Sargassum* will partly help us redress some of the environmental issues brought about by Global Climate Change. Now it is the time to turn this problem into opportunities.

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### Author's Contributions

**Gary Gervais and Jodany Fortune:** Conceived and designed the experiments.

**Clifford Louime:** Contributed reagents/materials/analysis tools and wrote the paper.

### Conflicts of Interest

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript and in the decision to publish the results.

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