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An investigation into the Pelagic Sargassum incursion phenomenon: A study of seaweed coastal influxes on Cozumel Island, Mexico

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ABSTRACT

The *Pelagic Sargassum* influx problem in Mexico and other Caribbean countries began in 2011 when seaweed arrived in extreme quantities on Mexican Caribbean coastlines. As coastal areas produce resources like fisheries, tourism, and raw materials, this creates problems for the surrounding businesses. *Sargassum* thrives in the Atlantic Ocean due to eutrophication, and the ocean conditions promote the shifting of these seaweed mats. This work aims to study *Sargassum* arrivals on Cozumel Island coasts and examine coastal lines disposition to receive the seaweed. From our findings, it was understood the importance of a good handling policy in the country and the disposition of sandy-type beaches to accumulate more *Sargassum*.

Keywords: Sargassum, golden tides, coastal management, Mexican Caribbean

INTRODUCTION

The *Pelagic Sargassum* influx problem in Mexico and various other Caribbean countries was first acknowledged in 2011 when the seaweed started arriving at Mexican Caribbean coastlines in extreme quantities (Chávez et al., 2020). *Pelagic Sargassum* reported large arrivals in eastern Caribbean Islands and African countries; the amount and frequency of these occurrences on the beach caused issues for the fishing and tourism industries (Franks et al., 2016), coastal areas are vital for the economy and population of these regions, as they provide important resources like fisheries, tourism, and raw materials (Schling et al., 2022).

The genus *Sargassum* is a type of brown macro-algae with 300 species found in both benthic and holopelagic environments. *Pelagic Sargassum* is composed of the species *Sargassum fluitans* and *Sargassum natans*. It is found in the Sargasso Sea, located in the Atlantic Ocean, and it is important because it gives a home to fish and other sea creatures (Rosa Elisa Rodríguez Martínez, 2015). **Figure 1** presents the *Sargassum* belt, which, since the first inundation in 2011, has grown and now extends from West Africa into the Caribbean Sea and the Gulf of Mexico.

Eutrophication, caused by nutrient-rich runoff from the Amazon River and West Africa, and ocean conditions change have led to *Sargassum* swarms. *Sargassum*'s ability to thrive in the Caribbean Sea is further aided by changes in oceanographic circumstances, such as variations in the water temperature (Brooks et al., 2019). Cozumel Island, part of the Mexican state of Quintana Roo, although is one of the most important tourist destinations in Mexico, is the area most severely impacted by these *Sargassum* blooms, with its tourism contributing almost 762 million USD to local economic activities only in 2021 (Lara-Pulido et al., 2021). Previous studies (Alcérreca-Huerta et al., 2019; Guzmán, 2019), show that the area with the greatest accumulation of floating *Sargassum* was detected in the Cozumel channel, between the island and the municipality of Solidaridad in Quintana Roo.

In the area surrounding the island of Cozumel, particular mesoscale-level oceanographic characteristics are recognized, which are assumed to be responsible for this maximum accumulation in relation to the rest of the region. This result, in the speculation that the *Sargassum* that enters the Cozumel channel has a high probability of reaching the beach, while the *Sargassum* that crosses the eastern portion of the Cozumel Island has a greater probability of continuing its northward movement driven by the strong Yucatan current (Alcérreca-Huerta et al., 2019). In a previous study made by Alcérreca-Huerta et al. (2019), it was presented that the southeast part of the island has a better disposition to receive and distribute *Sargassum* due to the currents that circulate in that location.

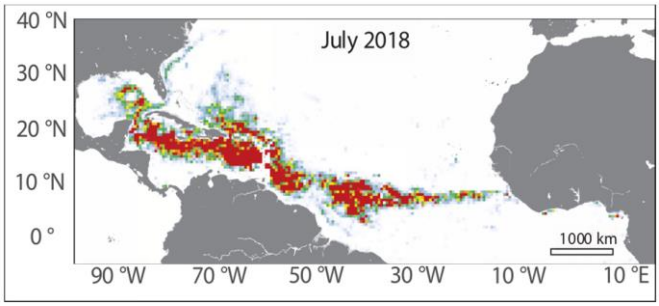

Figure 1. *Sargassum* belt 2018 (Wang et al., 2019)

Previous studies have emphasized the importance of monitoring *Sargassum* movement patterns and employing remote sensing techniques on beaches (Cuevas et al., 2018; Valentini & Balouin, 2020; Wang & Hu, 2017). However, limited research has focused on local management information, and only a few have proposed combining both approaches (Rutten et al., 2021; Uribe-Martínez et al., 2022). Although technological development is important at various times, most places in third-world countries, like Mexico, are still collecting the *Sargassum* manually and have not effectively established monitoring systems, such as monitoring via remote sensing, to combat the *Sargassum* overpopulation.

Nonetheless, given the island's heavy reliance on fossil fuels, alternative strategies, such as *Sargassum* biorefinery (Azcorra-May et al., 2022), are necessary. Therefore, studies like this one, which offer a clear and systematic understanding of the beaches with higher probabilities of *Sargassum* overaccumulation, could benefit strategies that include the utilization of the plant and increase the efficiency of collection methods for the generation, and establishment of renewable energies in Mexico.

This research aims to explore the occurrence of *Sargassum* on three specific beaches. These beaches were selected based on their morphological characteristics, such as beach type and their geographical position along the coastline. These factors combine to determine the disposition of each place to withhold the plant. As a result, we expect to offer information that will prioritize the cleanup efforts for certain beaches, mitigating the negative effects of *Sargassum* and saturating those areas.

MATERIALS & METHODS

Study Site

Cozumel Island is situated 19 kilometers off the mainland and 82 kilometers south of Cancun in the Caribbean Sea at the eastern edge of the Yucatan Peninsula. The island is about 48 km long and 16 km wide. It is Mexico's third-biggest island and the largest permanently inhabited island in the Caribbean, with a total size of 477.961 km^2, and a population of 88,626 people as of 2020 (INEGI, 2020). The western region of the island is, where tourism is growing because of the white sand beaches there. Hotels are concentrated on this side of the island, where the main urban area is located, and the island's commercial activity is prolific here (Palafox Muñoz & Zizumbo Villarreal, 2009). The eastern side is formed by a rocky coastline, including small bays with sandy-type beaches, where small businesses are found along this part of the coastline. The vast majority of these businesses are restaurants, handicraft shops, and motels. There are recreational beaches around the coastline (Mezcalitos, Punta Morena, Chen Rio, Playa Bonita, Punta Chiqueros, and El Mirador); from this list, we selected three specific beaches to be the subject of our study, which are represented in **Figure 2**:

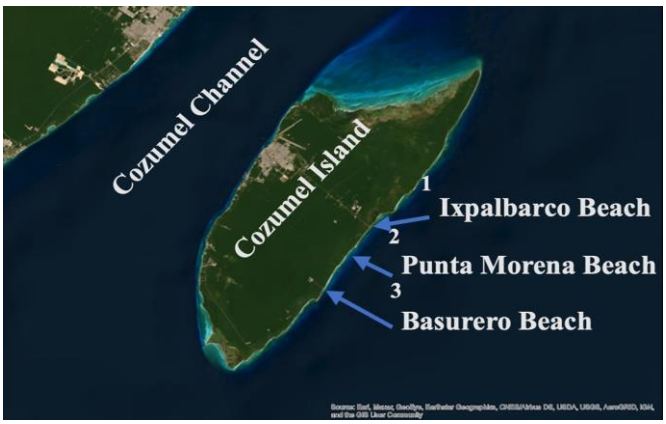

Figure 2. Cozumel Island with studied areas displayed (Modified from Esri, Maxai, Geoeye, Earthstar Geographies, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, & GIS User Community open source database)

1. Ixpalbarco Beach
2. Punta Morena Beach
3. Basurero Beach.

All these presented different morphological characteristics and have experienced every year a massive reach of *Sargassum* according to the local registers.

Method

In this study, *Sargassum* was removed from specific areas along the shoreline, where the seaweed accumulates. This fieldwork took place on October 2nd, 2021, on Cozumel Island; although, the *Sargassum* arrivals have their peak season during March through August (Chávez et al., 2020). The seaweed characterization was done from the lowest place on the beach, where the Sargassum started accumulating (low tides), until the highest place with *Sargassum* accumulation (high tides). The sea surface will often fluctuate by the effect of the tides, which start in the oceans and move toward the coastline. High tide is when the wave's highest portion, or crest, reaches specific areas; low tide is when the wave's lowest portion, or trough, happens (NOAA, 2023).

Initially, the collection process involved the renaming of each beach into three distinct profiles (A, B, and C). To measure each profile, it was used a one m^2 ruler, to delimit the area of collection, and remove about 10 cm of depth of *Sargassum*. The sampling was performed in the beginning, middle, and end, of each profile designated on each beach. It should be mentioned that in these profiles we did not just find *Sargassum* as the only biomass, but also, other plants, sponge bobs, and coconuts; having this in mind will prevent us from considering the plant as the only biomass coming from these recollection points.

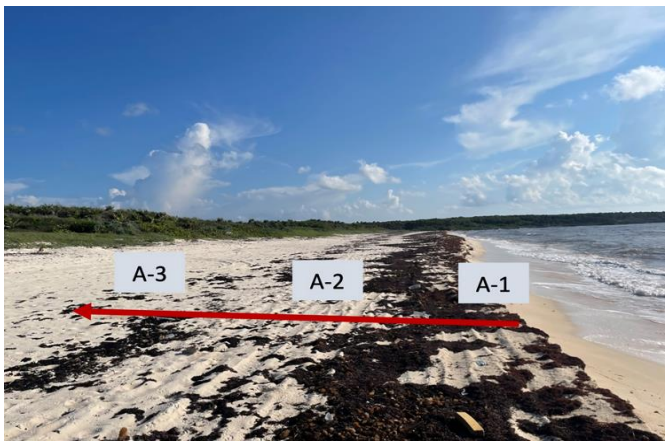

Figure 3. Ixpalbarco Beach (Source: Authors' own elaboration)

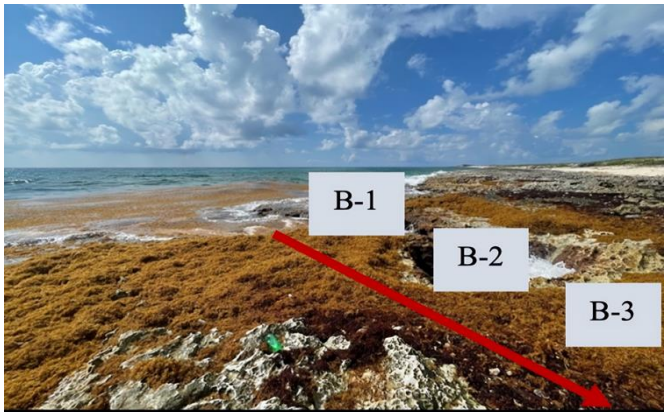

Figure 4. Punta Morena Beach (Source: Authors' own elaboration)

RESULTS & DISCUSSION

Ixpalbarco Beach

The first characterized beach was the "Ixpalbarco Beach" shown in **Figure 3**, which is located directly above the island's central coastal route. This beach is sandy-type, and because of its placement on the coastline and the influence of low tides, we encountered a substantial amount of dry *Sargassum* in this location (Trinanes et al., 2023). Ixpalbarco Beach was named "profile A" and it had a length of 6.7 meters, where *Sargassum* deposit could be seen. Profile A-1, the closest point to the water, showed some accumulation of *Sargassum* from beach, in this area is possible to see wet *Sargassum*, and at the bottom of the borderline the *Sargassum* that is arriving with the tides. There was no garbage found in this profile. The constant seaweed movement keeps fresh seaweed replacing the already dried plant and also avoids the overaccumulation of other wastes. Profile A-3 had almost no *Sargassum* accumulation, so we did not consider any *Sargassum* collected from this profile. It should be mentioned that in these profiles *Sargassum* was not the only biomass, but other plants, sponge bobs, and coconuts were found. It could be thought that when tide level gets stronger, more *Sargassum* will be deposited on the beach.

Punta Morena Beach

Driving down the Cozumel Eastern highway, there's Punta Morena Beach shown in **Figure 4**, which is a rock-type beach.

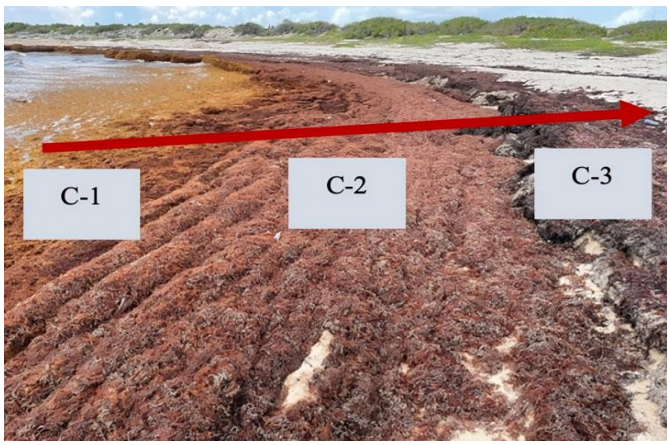

Figure 5. Basurero Beach (Source: Authors' own elaboration)

This place showed a massive accumulation of *Sargassum*. The deposition of the *Sargassum* on this beach comes mainly because of the strength of the tides, which pull the *Sargassum* mats along the coast and create a point of accumulation on these rocks. It is to be observed that even though this beach accumulates a lot of seaweed, the rocks make difficult its extraction or collection. The seaweed characterization for this beach was named "profile B". It was performed by dividing the length of 8.3 m into three parts of around 2.7 m, and then, we proceeded to remove one m^3 of seaweed.

Extracting the specific amount of *Sargassum* from this area was complicated due to the continuous movement of the waves and the instability that the *Sargassum* covering the rocks created in the place. Profile B-3 was measured in the furthest layer of *Sargassum* from the sea and it showed the plant already in a decomposition state, it was also noticed that it did not have a thick layer of *Sargassum* as the previous two, it was around 10 cm deep. Profile B did not show many plastics mixed with the seaweed as in comparison with profile A. The *Sargassum* in this profile B-3 showed an already decomposing plant with not only traces of plastic garbage but also other biomass waste, such as coconuts.

Basurero Beach

The third beach that was visited is called "Basurero Beach", which was in front of Cozumel's city landfill and is located 1 km away from the highway. This beach is thought to be one of the best locations for the recollection of *Sargassum*, attributable to its sandy shores and position in a bay, which is on the southeast side of the Island, where the currents collect the seaweed easily. In **Figure 5**, it can be observed that the shape of the bay forms a curve for this beach, allowing the Sargassum mats to arrive and stay closer to the beach.

The mats of *Sargassum* stay close to the beach and the energy that carries the mats. For its characterization, it will be named "profile C". **Figure 5** also shows how this beach displays three colors, Point C-3 is, where the plant is already dried and, in some cases, it shows decomposition signs. Point C-2 is, where decomposing *Sargassum* is more abundant, however, the plant shows greater signs of decomposition, and the odor and the number of larvae and flies in the area were remarkable. Lastly, point C-1 was, where the *Sargassum* was fresh by the action of the constant movement of the waves.

Table 1. Information collected from each beach

Beach	Tides	Beach type	Sargassum found	Sampled volume (m^3)	Collected amount (kg)	Sargassum recollection	Garbage found	Entities collecting on the beach
A	Low tides	Sandy	Dry	0.2	188	Feasible	Plastics, PET bottles, & fishing nets	Local government
B	High tides	Rock	Wet	0.3	282	Not feasible	Plastics, PET bottles, fishing nets, & sandals	None
C	High tides	Mixed	Wet	0.3	282	Feasible	Plastics, PET bottles, fishing nets, woods, & organic waste	Local government

Sargassum Collection in Cozumel

Public entities, such as ZOFEMAT and SEMARNAT, in Mexico have been working against the massive influxes of *Sargassum*, creating strategies and plans to handle the seaweed; their latest report, "Technical and management guidelines for the contingency occasioned by Sargasso in the Mexican Caribbean and the Gulf of Mexico", presents different steps regarding the handling of the plant (SEMARNAT, 2021). ZOFEMAT on Cozumel Island currently sends six to ten people daily to collect *Sargassum* from the coastlines. They work from 6 a.m. to 12 p.m., load the seaweed in trucks, and take it to deposition centers to combat the golden tides. The personnel uses pitchforks and nets to collect the seaweed and transport it to the trucks.

In **Table 1**, the findings made in each studied site are presented. It shows the beach profiles, the tides that are usually perceived, the type of beach, the physical state of the *Sargassum* found laid on the beach, the sampled volume, the amount collected, and the entities that are currently cleaning these places. These findings could contribute to solidifying an efficient cleaning and sorting strategy for the remaining beaches along the east coastline of Cozumel Island. The restaurants on this side of the island have been heavily affected by the golden tides and rely on the local population for support. The manual removal from the governmental institutions is not enough, therefore the business owners must collect the *Sargassum* themselves and deposit it alongside the road or treat it as a regular waste.

CHALLENGES FOR THE COLLECTION AND UTILIZATION OF *SARGASSUM*

Due to the affectation implied by the enormous masses of *Sargassum* that arrive on the beaches, the tourism industry in the Caribbean region has become one of the primary concerns of the Mexican government. Despite the possibility of collection, the volume of sargassum presents a significant challenge to public administration because it can worsen issues related to unemployment, social welfare, and health, which are already exacerbated by the large-scale sargassum landings on populated beaches (Uribe-Martínez et al., 2020). Studies report that in 2015 Mexico saw the worst influx of seaweed with 2,400 m^3/km of seaweed removed from the Caribbean beaches (Chávez et al., 2020). Public entities, in Mexico have been working against the massive influxes of *Sargassum*, creating strategies and plans to handle the seaweed. Current research has shown the bioavailability of *Sargassum* for being used as feedstock for anaerobic digestion or gasification processes (Thompson et al., 2020a) and the possibility of using it in co-digestion with food waste (Thompson et al., 2020b). These actions present opportunities for the usage of renewable energies in a country like Mexico, where in 2021 almost 87% of its energy production came from fossil fuels and only 12% came from renewable energies (EIA, 2023).

CONCLUSIONS

The golden tides situation in Mexico and the Caribbean is problematic and shows no signs of slowing soon. The current plan concerning the elimination and management of seaweed has demonstrated its lack of reliability. In this study, we found that sandy-type beaches are more suitable for Sargassum collection but not all of them present a constant overpopulation of the plant. Basurero Beach in the southeast bay showed that is more likely to have *Sargassum* because of its location and geographic characteristics. The findings can aid in the reduction of excessive seaweed on beaches by identifying comparable areas to Basurero Beach. Because of the high variability of *Sargassum* distribution in the Quintana Roo state, the information provided here can be used by the tourism industry and decision-makers in Cozumel Island to prioritize their monitoring and collection efforts, as well as to be prepared for unexpected *Sargassum* arrivals at any time of the year. Creating more reliable and sustainable *Sargassum* collection strategies can benefit local businesses and make Cozumel a more attractive tourist destination.

It should be noted that the equipment used to remove the plant, exposes not only the workers to rough and unhealthy working conditions but also, increases the risk of beach erosion by the constant haulage of seaweed mixed with the sand from the beach. Further research is necessary for the characterization of the remaining beaches on the island. By conducting additional onsite studies, it is possible to establish systematic guidelines that can prioritize areas requiring greater attention. Consequently, this can lead to an enhancement of the current collection strategies that take place on the Island.

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Ethical statement: The authors stated that ethics committee approval was not required for the study. Research involving

information readily available in the public domain, such as published biographies, newspaper accounts of an individual's activities, and published minutes of a meeting, is considered personal data under the Data Protection Act but does not require ethics review.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from corresponding author.

REFERENCES

Alcérreca-Huerta, J. C., Encarnacion, J. I., Ordoñez-Sánchez, S., Callejas-Jiménez, M., Barroso, G. G. D., Allmark, M., Mariño-Tapia, I., Casarín, R. S., O'Doherty, T., Johnstone, C., & Carrillo, L. (2019). Energy yield assessment from ocean currents in the insular shelf of Cozumel Island. *Journal of Marine Science and Engineering, 7*(5), 147. https://doi.org/10.3390/jmse7050147

Azcorra-May, K. J., Olguin-Maciel, E., Domínguez-Maldonado, J., Toledano-Thompson, T., Leal-Bautista, R. M., Alzate-Gaviria, L., & Tapia-Tussell, R. (2022). Sargassum biorefineries: Potential opportunities towards shifting from wastes to products. *Biomass Conversion and Biorefinery*. https://doi.org/10.1007/s13399-022-02407-2

Brooks, M. T., Coles, V. J., & Coles, W. C. (2019). Inertia influences Pelagic *Sargassum* advection and distribution. *Geophysical Research Letters, 46*(5), 2610-2618. https://doi.org/10.1029/2018GL081489

Chávez, V., Uribe-Martínez, A., Cuevas, E., Rodríguez-Martínez, R. E., van Tussenbroek, B. I., Francisco, V., Estévez, M., Celis, L. B., Monroy-Velázquez, L. V., Leal-Bautista, R., Álvarez-Filip, L., García-Sánchez, M., Masia, L., & Silva, R. (2020). Massive influx of pelagic sargassum spp. On the coasts of the mexican caribbean 2014-2020: Challenges and opportunities. *Water (Switzerland), 12*(10), 2908. https://doi.org/10.3390/w12102908

Cuevas, E., Uribe-Martínez, A., & de los Ángeles Liceaga-Correa, M. (2018). A satellite remote-sensing multi-index approach to discriminate pelagic Sargassum in the waters of the Yucatan Peninsula, Mexico. *International Journal of Remote Sensing, 39*(11), 3608-3627. https://doi.org/10.1080/01431161.2018.1447162

EIA. (2023). *Country analysis brief: Mexico*. https://www.eia.gov/international/content/analysis/countries_long/Mexico/mexico.pdf

Franks, J. S., Johnson, D. R., & Ko, D. S. (2016). Pelagic *Sargassum* in the tropical North Atlantic. *Gulf and Caribbean Research, 27*(1), SC6-SC11. https://doi.org/10.18785/gcr.2701.08

Guzmán Ramírez, A. A. (2019). *Análisis espacio-temporal de la distribución de sargazo (Sargassum natans y S. fluitans) en la costa de Quintana Roo, México* [*Spatio-temporal analysis of the distribution of sargassum (Sargassum natans and S. fluitans) along the coast of Quintana Roo, Mexico*] [Master's thesis, Universidad Autonoma Metropolitana].

INEGI. (2020). *Censo de poblacion y vivienda* [*Census of population and housing*]. https://censo2020.mx/

Lara-Pulido, J. A., Mojica, Á., Bruner, A., Guevara-Sanginés, A., Simon, C., Vásquez-Lavin, F., González-Baca, C., & Infanzón, M. J. (2021). A business case for marine protected areas: Economic valuation of the reef attributes of cozumel island. *Sustainability (Switzerland), 13*(8), 4307. https://doi.org/10.3390/su13084307

NOAA. (2023). *Tides and water levels: NOAA's national ocean service education*. https://oceanservice.noaa.gov/education/tutorial_tides/welcome.html

Palafox Muñoz, A., & Zizumbo Villarreal, L. (2009). Distribución territorial y turismo en Cozumel, Estado de Quintana Roo, México [Territorial distribution and tourism in Cozumel, State of Quintana Roo, Mexico]. *Gestión Turística* [*Tourism Management*]*, 11*, 69-88. https://doi.org/10.4206/gest.tur.2009.n11-04

Rosa Elisa Rodríguez Martínez, B. I. (2015). *The massive influx of pelagic Sargassum to the Caribbean coast of Mexico (2014-2015)*. Universidad Nacional Autónoma de México.

Rutten, J., Arriaga, J., Montoya, L. D., Mariño-Tapia, I. J., Escalante-Mancera, E., Mendoza, E. T., van Tussenbroek, B. I., & Appendini, C. M. (2021). Beaching and natural removal dynamics of Pelagic Sargassum in a fringing-reef lagoon. *Journal of Geophysical Research: Oceans, 126*(11), e2021JC017636. https://doi.org/10.1029/2021JC017636

Schling, M., Compeán, R. G., Pazos, N., Bailey, A., Arkema, K., & Ruckelshaus, M. (2022). The economic impact of Sargassum: Evidence from the Mexican Coast. *IDB*. https://doi.org/10.18235/0004470

SEMARNAT. (2021). *Lineamientos técnicos y de gestión para la atención de la contingencia ocasionada por Sargazo en el Caribe Mexicano y el Golfo de México* [*Technical and management guidelines for the attention of the contingency caused by Sargassum in the Mexican Caribbean and the Gulf of Mexico*]. https://www.gob.mx/semarnat/documentos/lineamientos-tecnicos-y-de-gestion-para-la-atencion-de-la-contingencia-ocasionada-por-sargazo-en-el-caribe-mexicano-y-el-golfo-de-mexico

Thompson, T. M., Young, B. R., & Baroutian, S. (2020a). Efficiency of hydrothermal pretreatment on the anaerobic digestion of pelagic *Sargassum* for biogas and fertiliser recovery. *Fuel, 279*, 118527. https://doi.org/10.1016/j.fuel.2020.118527

Thompson, T. M., Young, B. R., & Baroutian, S. (2020b). Pelagic *Sargassum* for energy and fertiliser production in the Caribbean: A case study on Barbados. *Renewable and Sustainable Energy Reviews, 118*, 109564. https://doi.org/10.1016/j.rser.2019.109564

Trinanes, J., Putman, N. F., Goni, G., Hu, C., & Wang, M. (2023). Monitoring pelagic *Sargassum* inundation potential for coastal communities. *Journal of Operational Oceanography, 16*(1), 48-59. https://doi.org/10.1080/1755876X.2021.1902682

Uribe-Martínez, A., Berriel-Bueno, D., Chávez, V., Cuevas, E., Almeida, K. L., Fontes, J. V. H., van Tussenbroek, B. I., Mariño-Tapia, I., Liceaga-Correa, M. de los Á., Ojeda, E., Castañeda-Ramírez, D. G., & Silva, R. (2022). Multiscale distribution patterns of pelagic rafts of Sargasso (Sargassum spp.) in the Mexican Caribbean (2014-2020). *Frontiers in Marine Science, 9*. https://doi.org/10.3389/fmars.2022.920339

Uribe-Martínez, A., Guzmán-Ramírez, A., Arreguín-Sánchez, F., & Cuevas, E. (2020). El sargazo en el Caribe Mexicano, revisión de una historia impensable [Sargassum in the Mexican Caribbean, review of an unthinkable story]. In *Gobernanza y manejo de las costas y mares ante la incertidumbre* [*Governance and management of coasts and seas in the face of uncertainty*] (pp. 743-768). Instituto de Ecología.

Valentini, N., & Balouin, Y. (2020). Assessment of a smartphone-based camera system for coastal image segmentation and Sargassum monitoring. *Journal of Marine Science and Engineering, 8*(1), 23. https://doi.org/10.3390/JMSE8010023

Wang, M., & Hu, C. (2017). Predicting Sargassum blooms in the Caribbean Sea from MODIS observations. *Geophysical Research Letters, 44*(7), 3265-3273. https://doi.org/10.1002/2017GL072932

Wang, M., Hu, C., Barnes, B. B., Mitchum, G., Lapointe, B., & Montoya, J. P. (2019). The great Atlantic Sargassum belt. *Science, 364*(6448), 83-87. https://doi.org/10.1126/science.aaw7912