Potential impacts of tropical cyclones on pelagic Sargassum

Chuanmin Hu[1]

[1]University of South Florida

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Abstract

In a recent study, Sosa-Gutierrez et al. (2022, https://doi.org/10.1029/2021GL097484) evaluated the potential impacts of tropical cyclones (TCs) on the Atlantic pelagic *Sargassum* using satellite-based *Sargassum* maps, 86 hurricane tracks during 2011 – 2020, and statistical analysis. The results showed an average drop of 40% in *Sargassum* coverage under TC trajectories, attributed to *Sargassum* sinking. However, there appear two issues: 1) the *Sargassum* maps contain large uncertainties due to methodology used in developing the maps. The impacts of these uncertainties on change detection are largely unknown, especially along the TC trajectories where cloud cover prevails; 2) there is a lack of a "control" experiment in the logic to infer causality. Based on these observations and arguments, while it is possible that TCs may have significant impacts, either positively or negatively, on pelagic *Sargassum*, a revisit appears necessary to use improved *Sargassum* maps and better experimental design before drawing conclusions.

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Chuanmin Hu, huc@usf.edu

Optical Oceanography Lab, College of Marine Science, University of South Florida
140 Seventh Avenue South, St. Petersburg, Florida 33773, U.S.A.

Abstract

In a recent study, Sosa-Gutierrez et al. (2022, https://doi.org/10.1029/2021GL097484) evaluated the potential impacts of tropical cyclones (TCs) on the Atlantic pelagic *Sargassum* using satellite-based *Sargassum* maps, 86 hurricane tracks during 2011 – 2020, and statistical analysis. The results showed an average drop of 40% in *Sargassum* coverage under TC trajectories, attributed to *Sargassum* sinking. However, there appear two issues: 1) the *Sargassum* maps contain large uncertainties due to methodology used in developing the maps. The impacts of these uncertainties on change detection are largely unknown, especially along the TC trajectories where cloud cover prevails; 2) there is a lack of a "control" experiment in the logic to infer causality. Based on these observations and arguments, while it is possible that TCs may have significant impacts, either positively or negatively, on pelagic *Sargassum*, a revisit appears necessary to use improved *Sargassum* maps and better experimental design before drawing conclusions.

Keywords: *Sargassum*, satellites, remote sensing, tropical cyclone, Atlantic Ocean

Plain Language Summary

Pelagic *Sargassum* in the Atlantic Ocean plays an important role in ocean biology and ecology, yet excessive *Sargassum* on beaches represents a nuisance. Recurrent blooms in the tropical Atlantic in recent years raise the question of how *Sargassum* may respond to tropical cyclones (i.e., hurricanes) as this is the same region where tropical cyclones form. While the question sounds simple, there is no easy answer due to the complexity in oceanography and limited knowledge in *Sargassum*. This commentary is meant to provide a cautious note on interpreting *Sargassum* changes after the passage of tropical cyclones.

1. Introduction

Blooms of the pelagic *Sargassum* (a brown macroalgae or seaweed) in the tropical Atlantic and the Caribbean Sea have been reported since 2011 (Gower et al., 2013; Schell et a., 2015; Hu et al., 2016; Ody et al., 2019), with a recurrent *Sargassum* "belt" discovered to stretch over a distance of > 8000 km from coast of west Africa to the Gulf of Mexico (Wang et al., 2019a, Gower and King, 2020; Fig. 1a). Such an emerging phenomenon stimulated multi-disciplinary research on their possible origins and causes (e.g., Sissini et al., 2017; Oviatt et al. 2019; Johns et al., 2020; Johnson et al., 2020; Jouanno et al., 2021) as well as on their consequences on carbon cycling, oceanic and coastal environments, local tourism, human health, and economy (Laffoley et al., 2014; Maurer et al., 2015; Hu et al., 2016; Siuda et al., 2016; van Tussenbroek et al., 2017; Baker et al., 2018; Krause-Jensen et al., 2018; Ortega et al., 2019; Rodríguez-Martínez et al., 2019; Gouvea et al., 2020; Paraguay-Delgado et al., 2020; Salter et al., 2020; Bach et al., 2021; Hu et al., 2021; Lapointe et al., 2021; Oxenford et al., 2021; Trinanes et al., 2021).

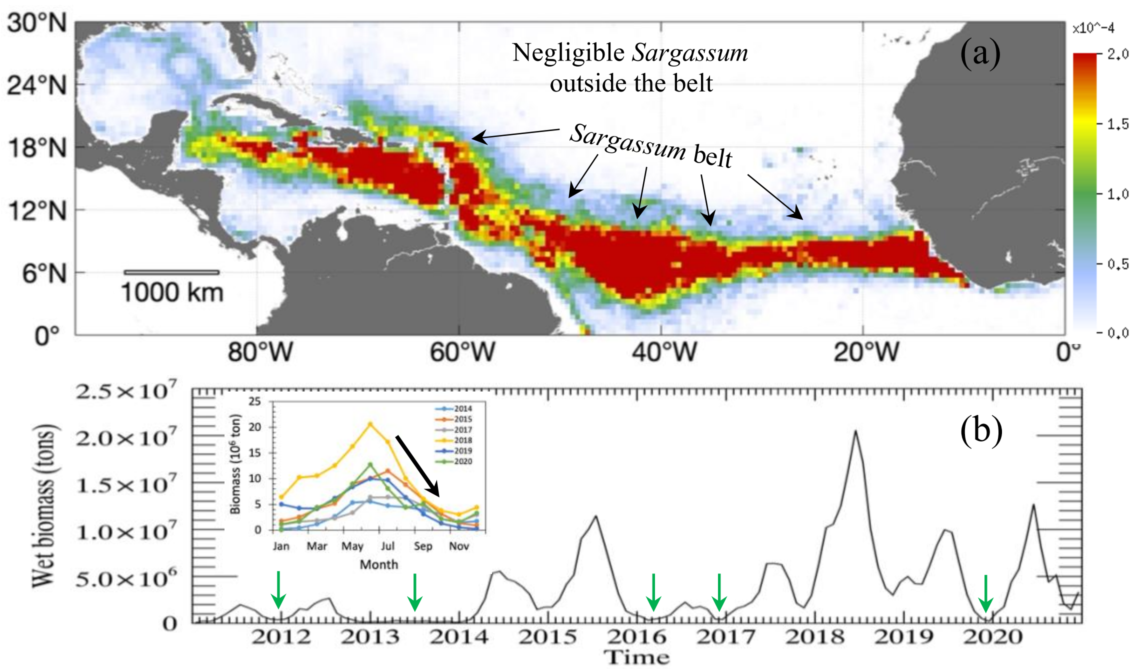

Fig. 1. (a) The Great Atlantic *Sargassum* Belt (GASB) from west Africa to the Gulf of Mexico, derived from MODIS satellite observations between 2011 and 2020 during the months of June – November (same period as in SG2022). Note that *Sargassum* amount is nearly zero outside the belt. Color legend indicates fractional cover (e.g., $1.0 \times 10^{-4} = 0.01\%$); (b) Monthly mean *Sargassum* biomass from the study region of (a). Note the ~20 million tons of biomass during the peak month in 2018 (Wang et al., 2019a), and minimal amount during most winter months and during 2013 (green arrows). The inset figure shows monthly variations in several major *Sargassum* years, where monotonic decreases start from June or July (black arrow). The data up to 2018 have been available at a public data repository (Wang et al., 2019b), with more recent observations of 2019 – 2020 amended here.

Because the *Sargassum* belt is mostly in the tropical Atlantic where frequent tropical cyclones (TCs, or hurricanes) can form, it is natural to ask how TCs may impact *Sargassum*. The answer to this question has significant implications because of the extensive relevance of *Sargassum* in the subjects mentioned above. In a recent study by Sosa-Gutierrez et al. (2022, SG2022 hereafter), the question has been addressed using satellite-based *Sargassum* maps, 86 TC tracks, and statistical analysis for the period of 2011 – 2020. From before-after comparisons, the statistics showed an average biomass decline of 40% within 200 km of selected anchor points along the tracks, which was further attributed to *Sargassum* sinking to deep waters.

However, the study appears to suffer from at least two issues to make it difficult to draw conclusions. These include: 1) large uncertainties in the *Sargassum* maps used in the study; 2) weakness in the logic to infer causality. Below I elaborate on these two issues and argue that while the topic is of particular importance for many reasons, a revisit appears necessary before drawing any conclusions.

2. Uncertainties in the *Sargassum* maps

Estimating *Sargassum* amount in a given location from satellite observations 700 km above the ocean requires sophisticated techniques and algorithms to convert the satellite-received signals to meaningful geophysical values (in this case, *Sargassum* percent cover or biomass per area). These include removing image pixels that are deemed invalid due to several factors (clouds, straylight, cloud shadows, sun glint, etc.), detecting *Sargassum*-containing pixels from the ocean background, pixel unmixing to determine sub-pixel proportion of *Sargassum*, conversion of areal cover to biomass, and pixel binning and averaging to generate gridded maps at monthly intervals. All these steps have been explained in detail in Wang and Hu (2016 & 2018) and Wang et al. (2018), which led to the discovery of the recurrent *Sargassum* belt as shown in Fig. 1a (Wang et al., 2019a).

In contrast, although the general concept of the above steps has been followed when developing methodology and generating the *Sargassum* maps used in the SG2022 study (Berline et al., 2020), several significant differences in the methodology led to large uncertainties in such derived maps. These include: 1) no pixel unmixing was used, so every *Sargassum*-containing pixel was treated the same even though the sub-pixel proportion of *Sargassum* may change by 2 orders of magnitude; 2) for a given grid within a month, every daily image was treated the same when calculating a monthly mean, regardless whether a daily image has 5% or 50% of valid pixels within the grid. There are other factors that can also lead to uncertainties (e.g., residual errors from removing noise and other artifacts), but the above two steps would lead to the monthly averages biased towards weak *Sargassum* signals and towards cloudy days (e.g., a 80% average determined from 5 valid pixels (i.e., 4 *Sargassum*-containing pixels) in Day 1 is weighted 8 times higher than a 10% average determined from 300 valid pixels (i.e., 30 *Sargassum*-containing pixels) in Day 2 even though the number of *Sargassum*-containing pixels in Day 1 is 8 times lower), thus leading to large uncertainties, especially over TC-adjacent waters due to frequent and rapid changes in cloud cover. The uncertainties due to #1 above are especially prominent because false-positive detection due to straylight or other image artifacts often results in pixels with low % cover, but these pixels have the same weights as those with much higher % cover when computing the mean or calculating statistics.

Such uncertainties are revealed in Fig. 1a of SG2022. Compared to Fig. 1 of Wang et al. (2019a) and Fig. 1a of this study where nearly no *Sargassum* is found outside the belt, Fig. 1a of SG2022 showed extensive measurable amount of *Sargassum* ($0.1 - 0.4 \times 10^{-4}$ fractional cover) nearly everywhere in the study region (8ºS – 32ºN, 100ºW – 0ºW of the Atlantic), as indicated by the light blue to dark blue colors in Fig. 1a of SG2022. Because the map is an average of 60 months between June and November of 2011 – 2020, any measurable color actually represents large amount of *Sargassum*, yet there is no field report of such amount of *Sargassum* in waters outside the belt, for example in SW of Gulf of Mexico or regions directly north and south of the *Sargassum* belt. Similar or even higher uncertainties may exist inside the belt because the belt coincides with the intertropical convergence zone (ITCZ) (Johns et al., 2020) where frequent cloud cover is found, but they are less visible in Fig. 1a of SG2022 due to the color stretch to highlight the belt.

The uncertainties are also revealed in Fig. 5 of SG2022. Compared to Fig. 3A of Wang et al. (2019a) and Fig. 1b above, Fig. 5 of SG2022 showed at least ~1 million tons of *Sargassum* even during winter months and during 2013, but the results in Fig. 3A of Wang et al. (2019a) and Fig. 1b indicate minimal amount in those months and during 2013 (green arrows). This discrepancy is believed to be due to the same reasons as mentioned above, which led to large uncertainties in the *Sargassum* maps used in SG2022. The problem with such uncertainties is that they do not represent a time-independent systematic bias, for otherwise the amount during summer months would be higher than shown in Fig. 1b by ~1 million tons. Instead, during the peak months of several major *Sargassum* years (e.g., 2015, 2018, 2019), *Sargassum* amounts are 15-25% lower in Fig. 5 of SG2022 than in Fig. 1b. All these differences suggest time-dependent, non-systematic uncertainties in the *Sargassum* maps used in the SG2022 study.

In summary, due to overweighting of weak *Sargassum*-containing pixels, overweighting of images with fewer valid pixels, and other specific treatments of image artifacts (straylight, cloud shadows, sun glint, etc.), the *Sargassum* maps used in SG2022 to assess TC impacts appear to contain large uncertainties. Such uncertainties may not be treated as time-independent or location-independent systematic biases but they may disproportionally depend on false-positive detections, which may further depend on cloud distributions that are strongly related to TC activities. Such uncertainties, when assessed on a relative scale, may also disproportionally depend on the absolute *Sargassum* amount, for example with much higher relative errors when the *Sargassum* amount is low (i.e., outside the belt in Fig. 1a of SG2022). Indeed, most of the TC positions (red dots in Fig. 1a of SG2022) used in calculating the statistics are located either on the edge of the belt or outside the belt with relatively low *Sargassum* amount. Therefore, with these *Sargassum* maps, it would be difficult to determine whether on average *Sargassum* amount did change after the passage of a TC.

3. Logic to infer causality

Even if all data (including the *Sargassum* maps) used in the SG2022 study were to be error free, it would still be difficult to draw conclusions because of a weakness in the logic used to infer causality. In the SG2022 study, before-after comparison statistics within 200 km of the TC points from the 86 TC tracks were used to infer causality, which may be problematic for several reasons. First, due to ocean currents and winds, it is unknown whether some of the *Sargassum* within the 200 km circle were transported outside the circle (i.e., a pure loss) after the passage of a TC. Likewise, it is unknown whether some of the *Sargassum* outside the circle were transported inside (i.e., a pure gain). Second, all TCs in the SG2022 study occurred in June – November, during which *Sargassum* is in the decline phase anyway when being treated as a whole (Fig. 1b inset, black arrow). In general, for a short-term time sequence within this period, decreased *Sargassum* may be observed even without the perturbation of TCs. For the calculated daily doubling rate of about -0.04 during many of these declining months (Wang et al., 2019a), the total *Sargassum* amount in the entire belt can drop by 56% (=1– $2^{(-0.04\times30)}$) in a month. Most of such drops are unrelated to TOCs when the belt is considered as a whole, as the seasonality appears to be natural. While there is no direct measurement to explain this seasonality, it is speculated that free-running circannual rhythms (CRs), which were found in other brown seaweed species (Lüning, 1994), may also be endogenous to control the timing of *Sargassum* growth or decline. This argument certainly does not rule out the possibility of impacts of TCs on a local scale. However, before other factors (e.g., horizontal transport) and the potential CR are ruled out, it would be difficult to attribute the post-TC *Sargassum* declines to TCs even if the declines were deemed realistic.

Indeed, detecting causality in complex ecosystems is always challenging (Sugihara et al., 2012). In the absence of several complete time-series to tease out the Granger causality paradigm (Granger et al., 1969), the task becomes even more difficult. Ideally, for post-event evaluations, a "control" experiment, similar to those used as the golden standards to determine causality in medical science, should be conducted. In such an experiment, all conditions are kept the same except one factor (i.e., TC). Obviously, such an experiment is impossible in the vast ocean. However, this should not preclude some careful experiments as alternatives. For example, during the same period of an event, a before-after comparison may also be conducted over a similar region but outside the event's footprint. If the post-event change in this "control" region is similar to the change within the event's footprint, then it is difficult to infer any causality. Likewise, within the event's footprint, if oceanographic conditions and *Sargassum* distributions are similar in other years but no event occurred in those years, analysis of possible changes in those years may also be helpful in interpreting post-even changes in the current year.

Such a weakness in the logic to infer possible causality is actually not unusual in the published literature when evaluating post-event ocean response in other regions and for other types of events. Therefore, due to the complex processes in the vast ocean, more caution is required when interpreting post-event changes.

4. Concluding remarks

By no means is this short commentary meant to diminish the value of the SG2022 study. Rather, the potential impacts of TCs and other natural events (e.g., dust deposition) on pelagic *Sargassum* have been understudied and therefore should be emphasized in future efforts. Meanwhile, the commentary is meant to serve as a cautious note when interpreting post-event changes in *Sargassum* amount and, in general, when interpreting post-event changes in other ocean properties. In the end, TCs might have significantly and negatively impacted *Sargassum*, but given the large uncertainties in the *Sargassum* maps and weakness in the logic when making inference of causality, it is premature to make any conclusions, and a revisit appears necessary to improve our understanding of how *Sargassum* may respond to TCs.

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References

Bach, L. T., Tamsitt, V., Gower, J., Hurd, C. L., Raven, J. A., and Boyd, P. W. (2021). Testing the climate intervention potential of ocean afforestation using the Great Atlantic Sargassum Belt. Nature Communications, 12:2556, https://doi.org/10.1038/s41467-021-22837-2

Baker, P., Minzlaff, U., Schoenle, A., et al., (2018). Potential contribution of surface-dwelling Sargassum algae to deep-sea ecosystems in the southern North Atlantic. Deep Sea Research Part II: Topical Studies in Oceanography, 148, 21-34.

Berline, L., Anouck, O., Jouanno, J., Chevalier, C., Andre, J-M., Thibaut, T., and Menard, F. (2020). Hindcasting the 2017 dispersal of *Sargassum* algae in the Tropical North Atlantic. Marine Pollution Bulletin, 158,111431, https://doi.org/10.1016/j.marpolbul.2020.111431.

Gouvea, L. P., J. Assis, C. F. D. Gurgel, et al., 2020. Golden carbon of *Sargassum* forests revealed as an opportunity for climate change mitigation. Sci. Total Environ. 729, 138745, https://doi.org/10.1016/j.scitotenv.2020.138745.

Gower, J., Young, E., & King, S. (2013). Satellite images suggest a new Sargassum source region in 2011. Remote Sensing Letters, 4, 764–773.

Gower, J., and King, S. (2020) The distribution of pelagic Sargassum observed with OLCI, International Journal of Remote Sensing, 41:15, 5669-5679, DOI: 10.1080/01431161.2019.1658240

Granger C. W. J. (1969), Investigating causal relations by econometric models and cross-spectral methods. Econometrica 37, 424.

Hu, C., Murch, B., Barnes, B.B., Wang, M., Maréchal, J.P., Franks, J., Johnson, D., Lapointe, B.E., Goodwin, D., Schell, J., 2016. Sargassum watch warns of incoming seaweed. EOS Trans. Am. Geophys. Union 97, 10–15.

Hu, C., M. Wang, B. E. Lapointe, R. A. Brewton, and F. J. Hernandez (2021). On the Atlantic pelagic Sargassum's role in carbon fixation and sequestration. Science of the Total Environment, 781, 146801, https://doi.org/10.1016/j.scitotenv.2021.146801

Jouanno, J., Moquet, J-S., Berline, L., et al. (2021). Evolution of the riverine nutrient export to the Tropical Atlantic over the last 15 years: is there a link with Sargassum proliferation? Environmental Research Letters, 16, 034042, https://doi.org/10.1088/1748-9326/abe11a.

Johns, E. M., R. Lumpkin, N. F. Putman, R. H. Smith, F. E. Muller-Karger, D. Rueda, C. Hu, M. Wang, M. T. Brooks, L. J. Gramer, and F. E. Werner (2020). The establishment of a pelagic

Sargassum population in the tropical Atlantic: Biological consequences of a basin-scale long distance dispersal event. Progress in Oceanography, https://doi.org/10.1016/j.pocean.2020.102269.

Johnson, D. R., J. S. Franks, H. A. Oxenford and S. L. Cox. 2020. Pelagic Sargassum Prediction and Marine Connectivity in the Tropical Atlantic. Gulf and Caribbean Research 31 (1): GCFI20-GCFI30. https://doi.org/10.18785/gcr.3101.15

Krause-Jensen D, Lavery P, Serrano O, Marba` N, Masque P, Duarte CM. (2018). Sequestration of macroalgal carbon: the elephant in the Blue Carbon room. Biol. Lett. 14: 20180236. http://dx.doi.org/10.1098/rsbl.2018.0236.

Laffoley, D., Baxter, J. M., Thevenon, F. and Oliver, J. (editors). 2014. The Significance and Management of Natural Carbon Stores in the Open Ocean. A Summary. Gland, Switzerland: IUCN. 16 pp.

Lapointe, B. E., R. A. Brewton, L. W. Herren, M. Wang, C. Hu, D. J. McGillicuddy, Jr., S. Lindell, F. J. Hernandez, and P. L. Morton (2021). Nutrient content and stoichiometry of pelagic Sargassum reflects increasing nitrogen availability in the Atlantic Basin. Nature Communications. 12:3060, https://doi.org/10.1038/s41467-021-23135-7

Lüning, K. (1994), When do algae grow? The third Founders' lecture. Eur. J. Phycol. 29, 61–67.

Maurer, A.S., De Neef, E., Stapleton, S., 2015. *Sargassum* accumulation may spell trouble for nesting sea turtles. Front. Ecol. Environ. 13, 394–395. https://doi.org/10.1890/1540-9295-13.7.394

Ody, A., Thibaut, T., Berline, L., Changeux, T., André, J.M., Chevalier, C., Blanfuné, A., Blanchot, J., Ruitton, S., StigerPouvreau, V., Connan, S., Grelet, J., Aurelle, D., Guéné, M., Bataille, H., Bachelier, C., Guillemain, D., Schmidt, N., Fauvelle, V., Guasco, S., Ménard, F., 2019. From in Situ to satellite observations of pelagic Sargassum distribution and aggregation in the Tropical North Atlantic Ocean. PLoS One 14, 1–29. https://doi.org/10.1371/journal.pone.0222584

Ortega, A., N. R. Geraldi, I. Alam, et al. (2019). Important contribution of macroalgae to oceanic carbon sequestration. *Nature Geoscience*, 12:748-754. https://doi.org/10.1038/s41561-019-0421-8.

Oviatt, C.A., Huizenga, K., Rogers, C.S., Miller, W.J., 2019. What nutrient sources support anomalous growth and the recent sargassum mass stranding on Caribbean beaches? A review. Mar. Pollut. Bull. 145, 517–525. https://doi.org/10.1016/j.marpolbul.2019.06.049

Oxenford, H.A.; Cox,S.-A.; van Tussenbroek, B.I.; Desrochers, A. (2021). Challenges of Turning the Sargassum Crisis into Gold: Current Constraints and Implications for the Caribbean. Phycology, 1, 27–48. https:// doi.org/10.3390/phycology1010003

Paraguay-Delgado, F., Carreño-Gallardo, C., Estrada-Guel, I., Zabala-Arceo, A., Martinez-Rodriguez, H.A., Lardizábal-Gutierrez, D., 2020. Pelagic *Sargassum* spp. capture CO2 and produce calcite. Environ. Sci. Pollut. Res. 27, 25794–25800. https://doi.org/10.1007/s11356-020-08969-w

Rodríguez-Martínez, R.E., Medina-Valmaseda, A.E., Blanchon, P., Monroy-Velázquez, L. V., Almazán-Becerril, A., Delgado-Pech, B., Vásquez-Yeomans, L., Francisco, V., García-Rivas, M.C., 2019. Faunal mortality associated with massive beaching and decomposition of pelagic *Sargassum*. Mar. Pollut. Bull. 146, 201–205. https://doi.org/10.1016/j.marpolbul.2019.06.015

Salter, M. A., R. E. Rodríguez-Martínez, L. Alvarez-Filip, E. Jordan-Dahlgren, and C. T. Perry (2020). Pelagic *Sargassum* as an emerging vector of high rate carbonate sediment import to tropical Atlantic coastlines. *Global and Planetary Change*, 195, 10332, https://doi.org/10.1016/j.gloplacha.2020.103332.

Schell, J. M., Goodwin, D. S., & Siuda, A. N., 2015. Recent *Sargassum* inundation events in the Caribbean: Shipboard observations reveal dominance of a previously rare form. Oceanography, 28(3), 8–10. https://doi.org/10.5670/oceanog.2015.70.

Sissini, M.N., De Barros Barreto, M.B.B., Szećhy, M.T.M., De Lucena, M.B., Oliveira, M.C., Gower, J., Liu, G., De Oliveira Bastos, E., Milstein, D., Gusmão, F., Martinelli-Filho, J.E., Alves-Lima, C., Colepicolo, P., Ameka, G., De Graftjohnson, K., Gouvea, L., Torrano-Silva, B., Nauer, F., Marcos De Castronunes, J., Bonomibarufi, J., Rörig, L., Riosmena-Rodríguez, R., Mello, T.J., Lotufo, L.V.C., Horta, P.A., 2017. The floating *Sargassum* (Phaeophyceae) of the South Atlantic Ocean - Likely scenarios. Phycologia 56(3), 321–328. https://doi.org/10.2216/16-92.1

Siuda, A.N., Schell, J.M., Goodwin, D.S., 2016. Unprecedented proliferation of novel pelagic *Sargassum* form has implications for ecosystem function and regional diversity in the Caribbean. Am. Geophys. Union, Ocean Sci. Meet. 2016, Abstr. ME14E-0682 2015.

Sosa-Gutierrez, R., Jouanno, J., Berline, L., Descloitres, J., & Chevalier, C. (2022). Impact of tropical cyclones on pelagic Sargassum. Geophysical Research Letters, 49, e2021GL097484. https://doi. org/10.1029/2021GL097484

Sugihara, G., May, R., Ye, H., Hsieh, C-H., Deyle, E., Fogarty, M., and Munch, S. (2012). Detecting causality in complex ecosystems. *Science*, 338(6106), 496-500. Doi:10.1126/science.1227079.

Trinanes, J., N. F. Putman, G. Goni, C. Hu, and M. Wang (2021). Monitoring pelagic Sargassum inundation potential for coastal communities. J. Operational Oceanography, DOI: 10.1080/1755876X.2021.1902682

van Tussenbroek, B.I., Hernández Arana, H.A., Rodríguez-Martínez, R.E., Espinoza-Avalos, J., Canizales-Flores, H.M., González-Godoy, C.E., Barba-Santos, M.G., Vega-Zepeda, A., Collado-Vides, L., 2017. Severe impacts of brown tides caused by *Sargassum* spp. on near-shore Caribbean seagrass communities. Mar. Pollut. Bull. 122, 272–281. https://doi.org/10.1016/j.marpolbul.2017.06.057

Wang, M., and C. Hu (2016), Mapping and quantifying Sargassum distribution and coverage in the Central West Atlantic using MODIS observations, Remote sensing of environment, 183, 350-367.

Wang, M., and C. Hu (2018). On the continuity of quantifying floating algae of the Central West Atlantic between MODIS and VIIRS, International Journal of Remote Sensing, 39:12, 3852-3869, DOI: 10.1080/01431161.2018.1447161.

Wang, M., Hu, C., Cannizzaro, J., English, D., Han, X., Naar, D., et al. (2018). Remote sensing of Sargassum biomass, nutrients, and pigments. Geophysical Research Letters, 45. https://doi.org/10.1029/2018GL078858

Wang, M., C. Hu, B.B. Barnes, G. Mitchum, B. Lapointe, and J. P. Montoya (2019a) The Great Atlantic Sargassum Belt. Science, 365: 83 – 87.

Wang, M., Hu, C., Barnes, B. (2019b). Sargassum density and coverage using Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data from 2001-01-01 to 2018-12-31 (NCEI Accession 0190272). NOAA National Centers for Environmental Information. Dataset. https://accession.nodc.noaa.gov/0190272.