A Network to Develop a Taxonomic, Monitoring, and Citizen's Participation Program for *Sargassum* Landings in Florida, Mexico, Barbados, and Brazil

Una Red Para el Desarrollo de un Programa Taxonómico, de Monitoreo y de Participación Ciudadana para las Arribazones de *Sargassum* en Florida, México, Barbados y Brasil

Un Réseau pour Développer un Programme de Taxonomie, de Suivi et de Participation Citoyenne pour les Arrivées de *Sargassum* en Floride, au Mexique, au Barbados et au Brésil

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ABSTRACT

The relatively recent mass landings of *Sargasssum* along the Caribbean, Brazilian, and African coasts, starting in 2011, are now not only an ecological threat, but also a threat to tourism, health, and fisheries. The problem of *Sargassum* landings increased in 2013 - 2015, and now, in 2018 we are witnessing the worst impacts to date. These landings are challenging scientists, coastal resource managers, and administrators at local, national, and regional levels as a new "normal" that urgently needs addressing. To improve outcomes, we need collaborative international coordinated efforts across the region. We are proposing a network of researchers that will:

i) Work on the development of protocols to involve citizens in a standardized monitoring of their local sites, and
ii) collect samples for resolution of taxonomic identity (through detailed morphological and molecular approaches) that will allow us to better understand the origins of the different spatial and temporal landings of *Sargassum,* and how future changes in climate and oceanographic conditions might influence future landings.

By involving citizens and an international network of researchers, we will be able to obtain region-wide data that will become publically accessible to add value to other research efforts and initiatives. The establishment of a network should also increase leverage to attract funds from different countries and sources to support further research and solutions to this difficult problem.

KEYWORDS: *Sargassum*, monitoring, taxonomy, citizen participation, regional

INTRODUCTION

The pelagic species of *Sargassum*: *Sargassum natans* (Linnaeus) Gaillon and *S. fluitans* (Børgesen) Børgesen, have historically formed the Sargasso Sea, the floating masses of these species that are retained within the North Atlantic Subtropical Gyre. The west and north boundaries are maintained by the Gulf Stream and North Atlantic Drift, while the eastern limit is more diffuse and maintained by the Canary Current. The North Equatorial Current and Antilles Current delimit the southern boundary. This "pelagic rainforest" is well known for its ecological importance and economic support for fisheries in the region (Laffoley et al. 2011).

Depending on oceanographic conditions, various places in the northern Caribbean and Gulf of Mexico receive landings of *Sargassum* that are important components of the beach dynamics. However, there has been a change in the abundance of *Sargassum* in the Gulf of Mexico over the last 40 years (Huffard et al. 2014). The relatively recent massive landings of *Sargassum* along the South Florida east coast and its expansion to other areas of the Caribbean, was thought to be part of this change (Webster and Linton 2013). However, massive landings have been observed since 2011 along the coasts of west Africa and Brazil, suggesting a different origin located to the east of Brazil (Gower et al. 2013). As reports of *Sargassum* landings in the eastern Caribbean islands increased, ocean currents were back-traced to confirm this new source region (Johnson et al. 2013), and satellite images were analyzed that corroborated these findings (Hu et al. 2016, Wang and Hu 2016, 2017). It is now evident that the new *Sargassum* phenomenon is Atlantic-wide and much more complex than originally thought, necessitating major efforts from scientists from different disciplines in order to understand its dynamics (Franks et al. 2016).

The large amount of biomass landing on the coasts has become a tourist, health and fisheries threat since 2013-2015,

and is challenging scientists, coastal resource managers and administrators at local and national levels (Rodriguez et al. 2017). The economic loses already happening at local levels is particularly dramatic for Caribbean countries that depend on tourism to sustain a large proportion of their economy and local fisheries as a major source of food.

This massive growth of *Sargassum* is still not fully understood, but potentially becoming the 'new normal' in the region in response to changes in oceanic conditions, particularly temperature increases driven by climate change, and nutrient enrichment from anthropogenic sources along Caribbean, African and Brazilian coastlines (Wang et al. 2018). Adaptation to this new situation demands a coordinated scientifically-sound plan of action. We need to understand the biology of these *Sargassum* species, including aspects such as their true taxonomic identity, their reproductive strategies, growth rates, mortality rates and responses to changes in temperature and nutrients. In addition to the basic scientific questions, we need to understand the impacts of different beach cleaning alternatives, which will depend on local conditions, managerial resources and volume of landings. We also recognize the need to analyze the costs to fishers and other coastal livelihoods as well as to the tourism industry.

To date, several studies have called attention to the problem and have demonstrated potentially large ecosystem impacts (e.g. Franks et al. 2011, Hu et al. 2016, Sissini et al. 2017, Tussenbroek et al. 2017). Other groups have invested significant efforts into developing educational and communication products regarding current state of knowledge and appropriate responses and best-practices for dealing with massive landings (e.g. Doyle and Franks 2015, Hinds et al. 2016, SPAW-CEP-UNEP, GCFI, FAO). Substantial efforts to improve forecasting of *Sargassum* influxes are also in progress, and beginning to provide publically accessible information. For example, the satellite -based *Sargassum* Watch System (SaWS) of the University of South Florida, Optical Oceanography Laboratory (https://optics.marine.usf.edu/projects/saws.html) is now a source of information covering the full region. Increasingly more institutional efforts are becoming accessible to the public. For example, the National Oceanic and Atmospheric Administration in collaboration with the Atlantic and Oceanographic Meteorological Laboratory are conducting a debris-monitoring program in the region, this team recently designed and added a floating device simulating drifting pelagic *Sargassum* to their monitoring program (http://www.aoml.noaa.gov/keynotes/PDF-Files/Jan-Feb2018.pdf). Another example of important efforts is the University of Southern Mississippi's web-based portal for reporting *Sargassum* strandings, although the entered data cannot be downloaded by the general public. These are examples of rapid responses that had mechanisms already in place for other problems and are now providing valuable information and examples for the organization of information such as monitoring and observation reporting, information that can support research and management.

However, the *Sargassum* phenomenon is of such magnitude that different working groups are needed in order to address the multiple questions that are still pending or arising as we learn more. We propose developing a network of interacting scientists that will share samples, data and methodologies to facilitate a much better understanding of the multiple issues regarding *Sargassum* influxes including taxonomy, monitoring landings, and development of a citizen-monitoring program that will help towards better management and adaptation to *Sargassum* landings in the region.

TAXONOMY

Two major questions need solution urgently:

i) What is the current taxonomic status of the two blooming species: *S. fluitans* and *S. natans*? and
ii) Are those the only species that are part of this bloom?

Currently there are 536 reported species of the genus *Sargassum* included in the algaebase (http://www.algaebase.org); of those, only 358 are fully accepted as valid species (Guriy and Guiry 2019). However, the taxonomy of the genus is a work in progress and as molecular studies continue, a different picture might emerge. For the pelagic species, the taxonomic community generally recognizes two species: *S. fluitans* and *S. natans* (see Littler and Littler 2000). Nevertheless, Parr (1939) recognized large morphological plasticity within those two species, and he described several morphotypes for each genus for specimens from the Gulf of Mexico, and presumed to be related to those of the Sargasso Sea.

Several efforts to organize the specimens landing along Brazil and the Caribbean into taxonomically recognized entities are in progress and suggest that there is a possible complex of species or, like Parr (1939) suggested, a complex of morphotypes within very few species. However, there are several discrepancies among studies and the taxonomic status remains confusing. For example, Schell et al. (2015) and Wrinn et al. (2016) have developed a field guide to identify several morphotypes of *S. fluitans* and *S. natans* following Parr's (1939) description. Széchy et al. (2012) published the verification of *S. natans* presence on the coast of Brazil, however their detailed morphological characterization differs from the two proposals mentioned above. Furthermore, Sissini et al. (2017) conducted a molecular study to identify *Sargasssum* species landing in Brazil, based on the genetic marker (ITS2), a commonly used marker for identifying species in this genus (Camacho et al. 2014). They found a robust group that included all pelagic species together, and suggested that there is only one single species rather than two species. It is noteworthy that Sissini's study could not distinguish between specimens believed to be *S. natans* and *S. fluitans*, nor among any of the different morphotypes. Due to the known large plasticity of species in this genus (Camacho et al. 2014), it is possible that the bloom is formed by very few species, or even single populations. Furthermore, since sexual reproduction is unknown to occur in the pelagic species, it is highly probable that the genetic divergence is very low among populations, and species. As such, we suggest that exploration of the genetic structure of the populations using microsatellites would be a good approach to distinguish potential sources of the populations landing in different geographic areas (Dudgeon et al. 2017).

It is evident that an in-depth taxonomic study is urgently needed to arrive at a consensus and to clarify the taxonomic status and thereby guide standardized monitoring programs and research into the biology and ecology of the *Sargassum* bloom species. This urgent need could be addressed by having a network of scientists from across the region who could share specimens and work together on advancing the knowledge.

MONITORING

The use of ecological indicators is paramount for the understanding of the dynamics of biological processes. In the case of the *Sargassum* influx, there is a real need to establish a long-term monitoring program, of standard ecological indicators, that covers the full geographic extent of the influx area (i.e. West Africa, Brazil and the Caribbean). There is also a need to provide *in situ* observations and quantitative estimations to advance the accuracy of the remote sensing methodologies currently being developed to predict *Sargassum* influxes (Franks et al. 2016). This could be solved by forming an international network that uses simple standardized monitoring protocols and reports quantitative as well as qualitative observations in an organized, shared, repository.

Successful monitoring programs use standardized methods, that are easy to calibrate, statistically sound, and simple enough to use tools and equipment available to all involved parties (Fourqurean and Rutten 2003, Cortez et al. 2019). However, to our knowledge, we still do not have a common protocol to monitor *in situ* the abundance of stranded *Sargassum*. To date there are a number of local efforts already in place, but each group is developing its own methodology to estimate abundance of the stranded *Sargassum* and the results are unlikely to be fully comparable. For example, some groups are concentrating on recording fresh landings while others include old stranded material. Different groups are using different sampling strategies such as permanent transects or random transects running perpendicular or parallel to shore and using different numbers and sizes of quadrats. Splitting the samples per species is also posing problems due to lack of training in distinguishing the different morphotypes and the current taxonomic confusion.

We suggest working together to develop standardized monitoring methods and then to support the monitoring and data collection by conducting calibration workshops and developing a 'training of trainers' course similar to the CAMPAM course for marine protected area managers (Bustamante et al. 2018).

CITIZENS PARTICIPATION

The participation of citizens in research that requires observations over large geographical extents is a practice that is becoming a common place in the fields of conservation and biogeography (Devictor et al. 2010). Many different citizen programs exist, some of them making use of technology such as mobile phone applications (e.g. https://www.inaturalist.org/, https://www.citsci.org.) and producing valuable monitoring data. While the amount and diversity of citizen projects is rapidly increasing, marine oriented citizen programs are still underrepresented compared with terrestrial programs. However, it is clear that citizen scientists can support long-term monitoring; they can also facilitate rapid responses and detection of stochastic events, and overall they can enhance research, management and conservation of ecosystems and species (Cigliano et al. 2014).

The massive influx of pelagic *Sargassum* onto beaches around the Caribbean is directly affecting a number of different local stakeholder groups and visitors, who could be targeted as potential participants in citizen's monitoring and reporting network. For example, many citizens and some visitors are already participating, in different capacities, in the cleaning of beaches (Figure 1 and 2). These individuals could be valuable sources of information, especially if reporting was built into the best practices being followed for clearing beaches. The use of a mobile phone app could greatly enhance the reporting and provide a rapid, semi-quantitative estimation of the abundance of stranded *Sargassum* throughout the region if the app made use of the simple photographic images depicting levels of severity developed by García-Sánchez and Tussenbroek (Table 1).

Another example could be to involve hotels that are taking charge of beach clearing to keep their businesses running, in a citizen participation network. A recent collaboration of hotels and researchers in the Mexican Caribbean have produced the first set of stranded abundance data and demonstrated that this is a robust and reliable method for increasing the area monitored if adequate protocols, developed by scientists in collaboration with hotel staff, are established (Rodriguez and van Tussenbroek, personal observations).

PROPOSED *SARGASSUM* NETWORK

In order to have an accurate picture of the dimensions and dynamics of the *Sargassum* influxes affecting the Caribbean, a robust, multi-layered, and international network is urgently needed to undertake collaborative monitoring and research. Useful lessons can be learned from a previous long-term, Caribbean-wide network (CARICOMP) that for 20+ years was involved in the monitoring of coastal productivity in coral reef, seagrass and mangrove ecosystems (Cortés et al. 2019) to build a strong *Sargassum* Network. We believe that the following lessons and structure illustrated in Figure 3 are of particular relevance for building a solid foundation for this network.

i) Ensure a broad geographic coverage of collaborators
ii) Develop a communication network
iii) Keep the monitoring protocol simple, low cost and standardized
iv) Start simple, and add complexity later depending on capacity of collaborators and questions being asked
v) Maintain a standard data templates and centralized data checking and repository
vi) Ensure open access data at least among collaborators
vii) Ensure funding for periodic meetings of collaborators for training, data analysis and publication

We are proposing to start very simple with the

development of a monitoring protocol to record *Sargassum* strandings as the core of the network. This can then feed into other areas of monitoring and research (Figure 1), such as sorting out the taxonomy, monitoring socio-economic impacts, and investigating heavy metal content of *Sargassum inter alia*. Interested parties are invited to join us in setting up this network.

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Figure 1. Hotel workers cleaning the beach. Bahía Príncipe, Quintana Roo México August 2018. Pictures Rosa Rodríguez-Martínez.

Table 1. Categories for rapid abundance estimation by citizens

Accumulation Category	Description of *Sargassum* accumulation	Water color	Anoxia?	Reduced light and pH?	Smell of decomposition?
Category 1	• No or very little *Sargassum* on the sand or beaches	Unchanged	No	No	No
Category 2	• Low accumulation of *Sargassum* on sand or beaches	Unchanged	No	No	No
Category 3	• Moderate to backing of *Sargassum* on the coast that causes a moderate accumulation on sand or beaches	Slightly Brown	No	No	No
Category 4	• Excessive overflow of *Sargassum* to the coast that causes a high or massive amount on sand or beaches • Forms mounds on seashore, < ½ m height)	Brown	Yes	Yes	Yes
Category 5	• Extremely excessive overhand of *Sargassum* to the coast that causes a very high or extreme accumulation of great extent on sand or beaches • Forms a mound barrier > ½ m height & floating in the sea.	Brown	Yes	Yes, significantly	Yes, very bad

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Figure 2. Stranded *Sargassum* in Puerto Morelos, Quintana Roo, México August 2018. Picture Elisa Vera

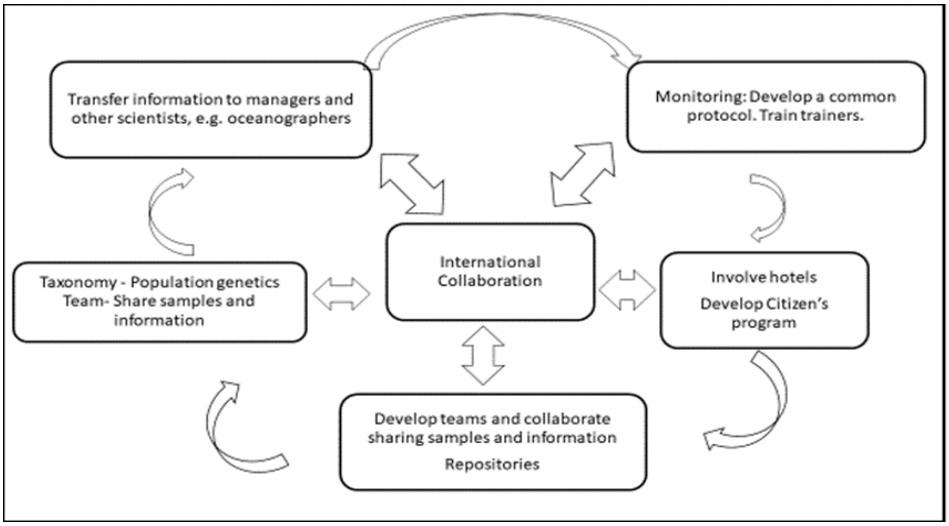

Figure 1. Conceptual vision of the network

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