

**Socio-environmental analysis of the impact of the massive arrival of
Sargassum off the coasts of Mexico and Belize**

Final Report

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The authors declare no conflict of interest. This research report poses the views of both, the interviewed people and the authors/ researchers, and not necessarily the positions of the Bonefish & Tarpon Trust (BTT) or El Colegio de la Frontera Sur (ECOSUR).

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1. Introduction

Throughout human history, many societies in different regions of the world have faced events, both natural and anthropogenic, that have altered their environment and livelihoods. Among the most extreme events are earthquakes and volcanic eruptions. Other less extreme events that have affected the productive and food systems worldwide are hurricanes and torrential rains, pests, invasive species and fires. The Caribbean Sea in the mid-Atlantic East region is no exception to these. This area includes the coasts of Belize and Quintana Roo in Mexico, Guatemala and Honduras which are facing an unprecedented arrival of sargassum. The coasts of these countries are part of the reef complex of more than 1,000 Km long called the Mesoamerican Barrier Reef System (MBRS), known as the world's second largest barrier reef. This coastal-marine region is known for its high species richness, scenic beauty, fishing productivity and recreational fishing (i.e., flats fishing). It is estimated that nearly two million people living in coastal communities with access to MBRS depend economically and culturally on its marine ecosystems (Kramer et al., 2015); that is, the MBRS is essential for fishers and tourism service providers, as well as other coastal workers, for them to pursue livelihoods (Palomo and Hernández, 2019). The economy of this region is primarily based on two main activities, which are fishing and tourism (Thomassiny-Acosta, 2010; Perez, 2012).

During the XX and XXI centuries, this region has been exposed to exogenous drivers which have impacted on the MBRS. Among those drivers are climatic variability including a higher frequency in hurricanes and storms (Konrad, 1996; Rivera-Monroy et al., 2020); bleaching coral reef events, the spread of the PaV1 virus in spiny lobsters (Lozano-Álvarez et al., 2008), the arrival of invasive species such as the lionfish (*Pterois* spp.) (Schofield, 2009; Vásquez-Yeomans et al., 2011), the stony coral tissue loss disease (van Woesik et al., 2020) and the massive arrival of sargassum (Rodríguez-Martínez et al., 2019). The present research addresses the atypical arrivals of sargassum, one of the latest external

drivers that has been impacting upon this region; particularly, our research focused on the impacts upon the coasts of Belize and Quintana Roo in Mexico.

Since 2011, the entire Caribbean region, including the coasts of Quintana Roo, Mexico and Belize, has been subject to the atypical, abundant arrival of sargassum (*Sargassum* spp.) This has had various impacts both, at the level of the complex of habitats that form the MBRS (i.e., dunes, mangroves, seagrass, reefs), the various productive activities of fishers and tourism service providers, as well as in general, that of coastal dwellers. Many of the studies addressing the region's impacts by sargassum have focused on the biological and ecological (Cabanillas-Terán et al., 2019; van Tussenbroek et al., 2017; Rodríguez-Martínez et al., 2019), biochemical (sargassum content) (Oyesiku and Egunyomi, 2014), satellite monitoring on its displacement at sea, as well as collection and adaptive to seaweed floods (Irvine et al., 2023). To a lesser extent, oceanographic aspects (Carrillo and Sheinbaum-Pardo, 2020), coastal erosion and the bio-technological use of sargassum have also been studied and explored. However, it is noteworthy that, despite the fact that, in most Caribbean countries, a large part of its populations are living on the coast, there are few studies on the effects of sargassum on these human populations. In particular, despite some general aspects of the effects that this seaweed has on coastal inhabitants are known (van Tussenbroek et al., 2017), little is known about the effects, medium and long term, on the health of those who deal with sargassum on a daily basis (Rosellón-Drucker et al., 2022a). It is also not known, if after more than a decade of coping with the arrival of sargassum on the coasts and their working areas, fishers and tourism service providers, as well as other coastal dwellers who have decades of interaction with the marine environment, have any innovative proposal that they can provide to the government of their country, to mitigate the effects caused by the arrival of this seaweed on their territories. Furthermore, it has been reported that, in the case of remote communities, such as island countries and other low-income countries, which do not have monitoring programs in place for the marine environment, the traditional knowledge of older people (fishers and coastal dwellers) is the only tool

available to decision makers, to know the historical changes of marine environmental conditions including fisheries (Johannes et al., 2000).

With respect on how the governments of Mexico and Belize are approaching the sargassum issue, two salient things are that they both are approaching it at a national level and that each government has been set programs and initiatives on sargassum in which there is still not much participation of the different coastal sectors. For instance, since 2019 Mexico has a permanent government-led program (under the responsibility of the Ministry of the Navy -Secretaría de Marina in Spanish) to address the massive arrivals of sargassum and has developed an integral sargassum management plan (SEMARNAT, 2021). In Belize a private-public Committee called 'Sargassum Task Force' has been in place since 2016; its Chair is the Ministry of Tourism and Civil Aviation (BHC, 2019). Despite the different policies of the governments of Mexico and Belize to manage the massive arrival of sargassum, the institutions, through governmental officers, should initiate and maintain a dialogue on sargassum impacts with fishers, tourism service providers, and the population of coastal communities in general. The latter would inform governmental authorities on how to devise and implement effective public policy on sargassum. It is essential to create a dialogue, as peers, for governments to identify and evaluate the relevance of recommendations, strategies and ideas in the management of the massive arrival of sargassum by coastal workers, recognizing their daily and first-hand experiences with the coastal and marine environment, as well as the critical review of current management practices of this seaweed by these sectors.

To help fill the information gap on sargassum studies, the present research was aimed at carrying out a socio-environmental analysis of the impact of the massive arrival of sargassum upon the coasts of Quintana Roo, Mexico and Belize. More specifically, our study has the following three specific objectives:

i) To identify the main socio-environmental issues in terms of ethnoecology and basic ecology, economic, social and cultural problems caused by the arrival of

sargassum in 14 Caribbean coastal communities from Quintana Roo, Mexico and Belize.

- ii) To analyze similarities and differences in the results obtained in Mexico and Belize in terms of basic ecology and social, economic and cultural aspects.
- iii) To write down a final report's section with recommendations and strategies proposed or identified by the social subjects interviewed to address or mitigate the problem of sargassum in the communities of the study area.

The present report is structured in four main sections. After this introduction, the second part describes the methodology including the theoretical approach, key concepts and methods used. The third part introduces results and discussion, describing the impacts caused by the arrivals of sargassum including a section with recommendations and strategies proposed by interviewees to improve the management of sargassum at their territories. The fourth part contains concluding remarks considering the objectives of our study and provides expert opinion from the research team to move forward in what the social actors recommended on sargassum management.

2.Methodology

2.1. Theoretical approach

Our research used a socio-environmental system framework of transdisciplinary nature, where its social component includes the coastal communities of Quintana Roo, Mexico and Belize, while its environmental part is delimited by the coastal-marine territory where the MBRS is located (comprising peoples' working areas of the social component). Moreover, our study considered that the socio-economic and cultural well-being of the coastal communities in our study area is based on two major livelihoods, fishing and tourism.

The word 'transdisciplinary' was used by Piaget in the early seventies (Piaget, 1972). Literature review reveals that there are different definitions of the words transdisciplinary and transdisciplinarity. In reviewing their etymological origin, the

scientist Basarab Nicolescu reports that the prefix "Trans" "is a Latin word meaning at the same time, in between, across, and beyond." (Volckmann, 2007, p. 78). In other words, "Transdisciplinarity is completely different [to interdisciplinarity] in the sense that it puts the problem of the information that circulates in between disciplines, across disciplines, and even beyond any discipline" (Volckmann, 2007, p.77). Other complementary views of transdisciplinarity indicate that it is the amalgamation of scientific knowledge with social practices (Lang et al., 2012), which is context-specific and where power relations and interculturality generally emerge (Zamora, 2020; Bello-Baltazar et al., 2020). Several authors recognize transdisciplinarity as a relatively new concept (Choi and Pack, 2006; Volckmann, 2007) and one that can be regarded as a tool, but also as an unfinished project permanently under construction (Max-Neef, 2005).

The transdisciplinary aspect of our study is found in the design of the research. It has to do with how the research was conceived and how it was carried out. In our study design, two principal researchers, one in two fields, marine biology and interdisciplinary studies, and another in social anthropology, discussed what research approach could be used in Mexico and Belize. The approach designed for Mexico was latter on discussed with two researchers from the Bonefish & Tarpon Trust in order to adapt it to Belizean communities.

In theoretical terms, our study is based on the fact that, through the fishing and tourism activities that are carried out in coastal territories, there is an encounter and an interrelation of social processes with ecological processes (Parra-Vázquez and Arce-Ibarra, 2022). In other words, throughout the MBRS territory and its landscapes and ecosystems (the coral reef, flats, mangroves, among others), every time a fishing activity and a tourism activity are carried out, there is an encounter of social processes with ecological processes. This results in the object of study called the socio-environmental system (*sensu* Parra-Vázquez and Arce-Ibarra, 2022).

In our study area's socio-environmental system, there are three main groups of social actors interacting with each other, namely, i) small-scale fishers, recreational fishers, and tourism service providers; ii) academic and civil groups conducting research or capacity building in these areas, and iii) authorities of the three levels of government (municipal, state and federal) and entrepreneurs (Figure 1).

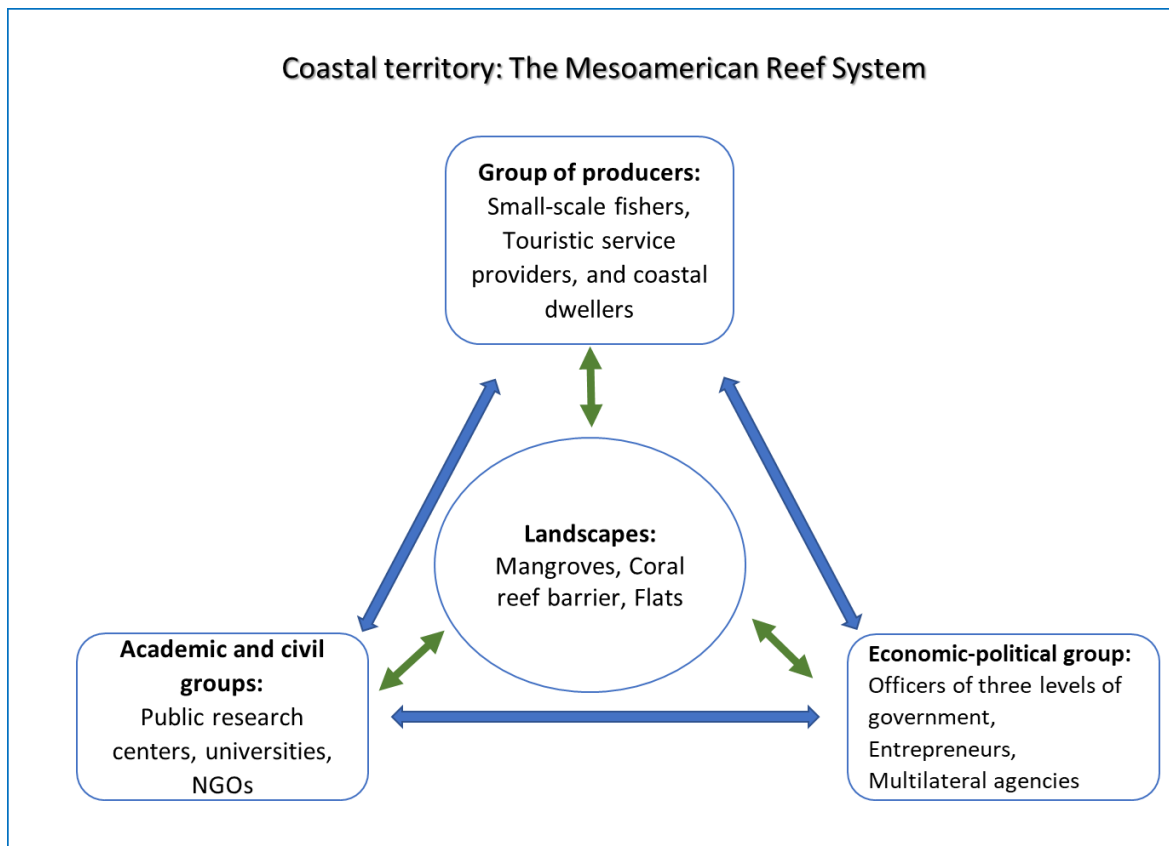


Figure 1. Main components of the analytical model called Local Socio-Environmental System (LSES) for our study area. Source: adapted from Parra-Vázquez et al. (2020).

Apart from transdisciplinary and transdisciplinarity, our research used several others theoretical concepts, which are the following: coastal- marine territory, ethnoecology, governance, natural resource management, and adaptive strategy. For this study's purposes, we define the coastal-marine territory as a socially constructed entity in constant transformation due to exogenous and endogenous factors. Communities (collectives or micro-societies) that inhabit a territory

appropriate it and use their worldview and traditions to grant it tangible and intangible values (Giménez, 1996; Peña-Azcona et al., 2020).

We refer to ethnoecology (ethno = people) as both, the accumulated knowledge and wisdom of people who have decades of interaction with the environment, in this case, with the marine environment. Thus, an ethnoecology related to the sea and the MBRS, we regard it as a branch of knowledge that studies the form and structure of the cognitive system that people have over the sea and the MBRS. At our study area, people's ethnoecological knowledge has been acquired by observation, as well as by trial and error, when people pursue their livelihoods at the coastal-marine territory. Most often, this knowledge has been transmitted from grandparents and parents to children, which was essentially acquired through practice (Toledo, 1992). This knowledge is often referred to in the literature as local or traditional knowledge, whereas the knowledge of aboriginal people is referred to as indigenous knowledge (Berkes, 2015).

With respect to governance, in the XXI century, theoretical approaches related to this concept define it as the total interactions between public and private actors, to solve problems and create opportunities (Guerrero-de León et al., 2010). Because of these actors' interactions, Kooiman and Bavinck (2005, p.12) coined the concept of 'interactive governance', which includes collaborative work among decision makers with local natural resource users (i.e., the communities), academia and the private sector. Following Kooiman and Bavinck (2005), in order 'to get the picture right', the actors involved in governance of any complex problem, and in this case of the massive sargassum arrivals, public and private actors should maintain a permanent process of communication and interaction.

We refer to natural resource management as the integrated process of planning, decision-making, allocation of natural resources, rules of use and enforcement, if appropriate, all directed toward the accomplishment of the agreed management objectives (Arce-Ibarra, 2007). The knowledge on the management of sargassum is still evolving. In Mexico sargassum arrivals are regarded as both, 'resource'

when this seaweed is alive at sea, which can be used or exploited, and 'waste' when it is decaying at the shores, which can be collected for disposal (CONACYT, 2022).

In ecology the term adaptation “refers to any response that increases the likelihood of population survival. In anthropology and development studies (...), adaptation is analyzed through resistance and adaptive strategy mechanisms, which are distinguished by time and are multiscale in nature. Resistance mechanisms are defined as the set of responses to short-term situations that increase the risk to livelihood systems. They take the form of an emergency response during anomalies in average weather and can overlap temporally. Over time, resistance mechanisms can develop and turn into adaptive strategies. Thus, resistance mechanisms arise at the individual or familial level whereas adaptive strategies, which are related to cultural values, arise from a larger spatial scale (Berkes and Jolly, 2001; Mosberg and Eriksen, 2015)” (Infante-Ramírez and Arce-Ibarra, 2019, p.80).

2.2. Methods

Our field work was carried out from October 6, 2022, to March 27, 2023, and encompassed a total of 14 communities from Belize and Mexico (Figure 2). In Mexico, the communities were (from North to South): Puerto Morelos, Playa del Carmen, Cozumel, Punta Herrero, Mahahual, and Xcalak. Moreover, four interviews (of people that used to go back and forth from Mahahual and Punta Herrero to Chetumal) were held in Chetumal.

In Belize, the studied communities were (from North to South): San Pedro, Caye Caulker, Belize City, Dangriga, Tobacco Caye, Hopkins, Placencia, and Punta Gorda. At both, Belize and Mexico, our study was aimed primarily at commercial and subsistence artisanal fisheries sectors and tourism sector, as service providers which includes the recreational fishing sector (e.g., the flats fishery).

Mexico

In Quintana Roo, Mexico, the tourism sector was represented by tourism service providers, recreational fishing guides, snorkeling guides, diving guides and tour operators. Apart from that, there were several touristic cooperatives which work as tour operators; we interviewed people in two of them. To a lesser degree, beach club staff and entrepreneurs (hotel and restaurant owners) from the tourism sector were also interviewed.

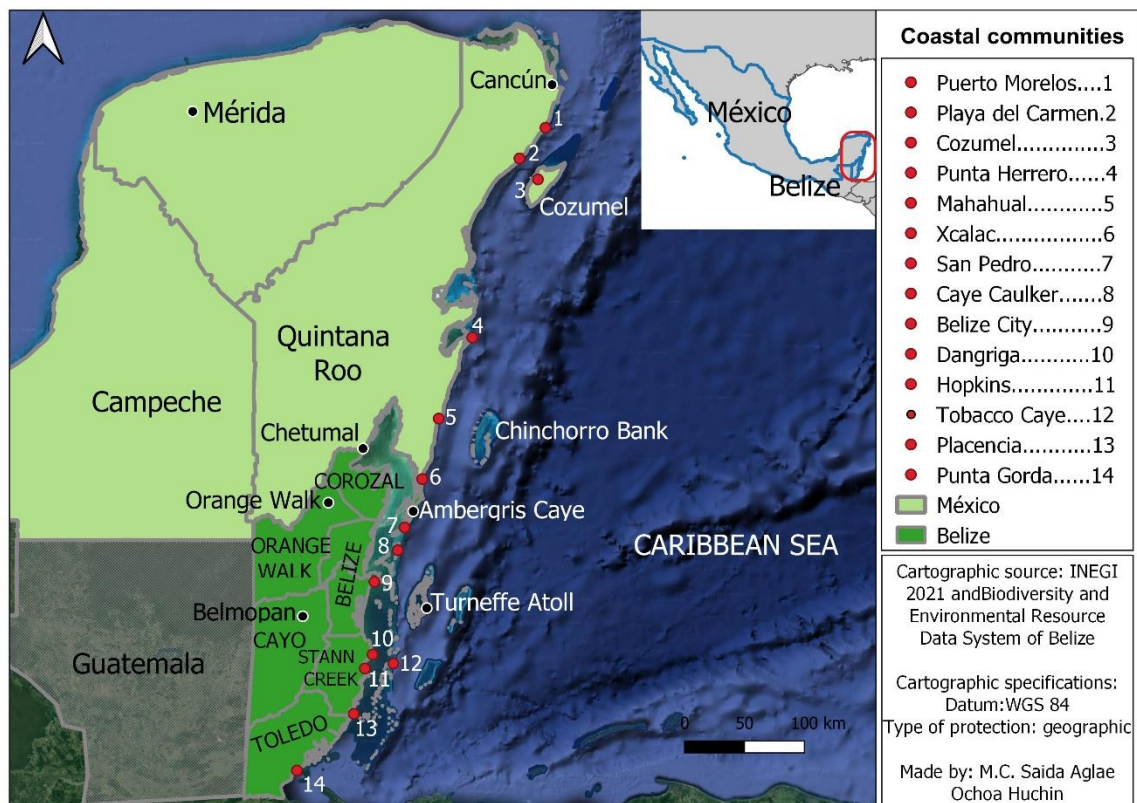


Figure 2. Study area. Communities from Quintana Roo, Mexico (numbers 1 to 6 plus Chetumal city) and Belize (numbers 7 to 14).

To put into practice the use of tools for collecting sargassum-related data, we decided to do most of the field work first in Quintana Roo, Mexico, where the data collection was carried out in Spanish. Therein we used the following field tools: a questionnaire with written questions and a 'focus group' meeting, as well as a field diary and our own field observations. The former two tools contained questions about the impacts of sargassum on the ecological, economic, social and health,

and cultural aspects. There were questions regarding the collection and disposal of sargassum and on the programs or initiatives carried out by the government on sargassum management. The last section of the questionnaire and the focus group contained a specific question, which is the following: what would you propose to address the sargassum problem in your country?

To apply the questionnaire, different people were invited to participate in our study. About 50% of them were people known to someone from our research team; that is to say, they are part of our collaborative networks that have had working interactions with a member of the research team in previous studies or in scholarly events. The rest of the interviewed people were coastal workers we did not know before. Once we invited each person to collaborate in our study, on some occasions, several people answered that, they could have a chat with us, but did not want to answer questions from any questionnaire; in these cases, we held open interviews on the problem of sargassum.

Regarding the focus group, 6 people participated in it, plus 4 people from our research team who oversaw the logistics of the meeting. From the 6 former people, 2 of them were instructors and guides of a private diving club; 1 was SCUBA instructors' assistant; 2 more were from a cooperative that offers tourist services, including recreational fishing, and 1 was from an artisanal fishing cooperative.

Belize

Once the research group gained experience asking about the impacts of sargassum in Mexico, we moved to Belize to do the field work. Similar to Mexico, in Belize, the tourism sector was represented by tourism service providers, recreational fishing guides, snorkeling guides, diving guides and tour operators. To a lesser degree, beach vendors, hotel and restaurant managers, entrepreneurs (hotel owners) from the tourism sector were also interviewed. Additionally, we also interviewed a worker who cleaned the beach from rotten sargassum.

However, on the recommendation of the staff of the Bonefish & Tarpon Trust (BTT), who know the uses and customs about how to carry out an interview and a talk of a research project in Belize, we did the work without using a questionnaire with written questions, but only by asking the questions verbally. That way of interviewing, we did it using a research's topic list, which we previously agreed on, like the topics we used during our field work in Mexico.

With respect to the focus group tool for Belize, it was planned to be held in Caye Caulker; however, three out of four the people who were invited as participants did not show up at the agreed meeting place. Hence, the gathering was cancelled.

Belize's field work was completed primarily (about 65%) with people who generally collaborate in other projects and in training courses with the BTT or who are people they trust. The rest of the people were coastal workers we did not know before. In the northern part of Belize, the questions were asked mainly in the Spanish language and, when the person interviewed requested it, the interview or talk was done in English. In the central and southern parts of Belize, we mainly used English for interviews; however, some people spoke fluent in Spanish (because they were descendants of Mexican or Guatemalan parents) and they themselves decided to talk to us in Spanish.

In addition, in the two countries under study, we held open talks and interviews with four authorities who work in the management of sargassum or who know its problems. In Quintana Roo, Mexico, we spoke with a mayor and a municipal undersecretary of ecology; and in Belize, with a City Councilor (Town Councilor) and with a Head of Community Authority (Chairlady). Also, given that co-management (shared management of protected natural areas) is recognized in Belize, we spoke with NGO staff who are co-managers of two protected areas, the Turneffe Reserve and the Hol Chan Reserve.

Regarding analyses of the collected information, once the fieldwork was finished, we organized the responses by topic and did a grouping (*a posteriori*) of them into the following four major themes, a) Informing society about sargassum and its potential effects; b) Local preparation for the arrival of the sargassum; c) Improving the management of the sargassum including mitigation strategies carried out by the government; and d) Research proposals for the scientific community.

In relation to ethical aspects of our research, for the fieldwork in Belize, the ethical recommendations posed by the BTT were followed; while, for Mexico, we considered the protocol of ECOSUR's Research Ethics Committee. During our talks, all the people interviewed in the two countries gave prior and informed consent to be able to interview them; in addition, when we consider it necessary, we ask for permission to record the interview.

In all cases, the people who agreed to collaborate in our study were told that the information they would give us would be anonymous and that it would be used only for the purposes of our research. Therefore, our results section maintains the anonymity of the people interviewed; therefore, when presenting some extracts of their answers in textual form, only the number of interview and country of residence were included.

3. Results and discussion

We interviewed a total of 77 people (53 men and 24 women) in 14 communities (7 in Mexico and 8 in Belize). Although these people primarily belonged to the group i) of the Local Socio-Environmental System (LSES), namely small-scale fishers, recreational fishers, and other tourism service providers, there were also some interviewees from groups ii) academic and civil groups, and iii) authorities and entrepreneurs. We found that these three main groups of social actors were also the main stakeholders on sargassum issues in both Mexico and Belize.

In Mexico, 40 people (31 men and 9 women) with an age range of 19 to 71 years, accepted to take part in our study, whereas in Belize, there were 37 participants (22 men and 15 women) ranging in age from 19 to 73 years.

3.1. Sargasso's socio-environmental impacts at the study area¹

In general terms, according to the two groups of people interviewed in the two countries, the massive arrival of sargassum from 2011 to date, has caused ecological impacts on the marine environment, as well as economic, social, cultural and health impacts on people who pursue livelihoods in their coastal territories. Most often, these impacts are interrelated which make the issue of sargassum a wicked problem (*sensu* Jentoft and Chuenpagdee, 2009). We found that most impacts of sargassum on the marine environment have consequences for coastal inhabitants in their social, economic, health and cultural aspects.

The two groups of people interviewed informed us that through time, atypical sargassum influxes have been gradually increasing, both, in the volume and space of the biomass that arrives, and throughout the year. They told us that, gradually, from 2014 to date, there have been several seaweed arrivals that have flooded beaches of their communities, as well as the eastern part of the islands of our study area (see Figure 2). Based on both, interviewees' responses and our own observations, and using a qualitative scale of impact (i.e., the most impacted; the moderately impacted, and the low impacted), we found that the coastal areas most impacted by sargassum in Mexico were Xcalak, Mahahual and Punta Herrero, as well as nearby areas. We found moderate impacts in Playa del Carmen, Puerto Morelos, and Cozumel. In Belize, the most impacted areas were the eastern areas of San Pedro in Caye Ambergris, Caye Caulker and Tobacco Caye; and moderately impacted, Turneffe, Dangriga, Hopkins and Placencia. The Belizean site that appears to have low impacts from sargassum is Punta Gorda (Figure 2).

¹ This section introduces the results of the following objective: i) To identify the main socio-environmental issues in terms of ethnoecology and basic ecology, economic, social and cultural problems caused by the arrival of sargassum in 14 Caribbean coastal communities from Quintana Roo, Mexico and Belize.

3.1.1. Ecological impacts

Interviewees from the two countries informed us that sargasso's ecological impacts are of two types, namely, positive and negative. A positive ecological impact of this seaweed is related to the fact that its biomass is the habitat of diverse marine fauna; that is to say, local people know that, in the arriving sargassum inhabits a great richness of species. In this vein, some tour guides, particularly those who use to dive and snorkel at the reef, have observed that, in some small parts of the reef, local biodiversity and abundance, especially of fish, appear to have increased due to the arrival of sargassum. Moreover, many of the species that sargassum brings, including crustaceans and fish, are part of the food of several of the target species of recreational fishing. Then, when the abundance of the arrival of sargassum off the coasts, ranges from little to moderate, recreational fishers take advantage of this to have good catches.

However, when sargassum arrives abundantly to the coast, recreational fishing is severely affected as it cannot longer be practiced. Moreover, local knowledge informed us that large, atypical influxes of sargassum result in death of many fish species as well as other flora and fauna. The common fish names mentioned as observed dead, floating in the water, were sardines, bonefish, angelfish, parrotfish, snapper, lionfish, puffer fish, among others. This ecological impact at the shores negatively impacts recreational fishing and commercial and subsistence fishing on community docks. We were told that the latter have impacted negatively the food security of fishers and their families.

Interviewees also informed us that seagrass and several areas of coral are being severely damaged by the arrivals of sargassum. The latter findings have been also reported by researchers in Mexico, who, based on expert opinion foresee that this damage may take decades to recover (van Tussenbroek et al., 2017).

With respect to the spiny lobster (*Panulirus argus*) fishers interviewed in Mexico, who catch lobster using shades or “casitas”, stated that sargasso arrivals do negatively impact on their catches. In contrast, except one fisher in Cozumel, who stated that abundance of lobsters in deep waters has been decreasing, fishers who capture spiny lobster (*P. argus*) by diving in Mexico and Belize commented that sargassum does not affect their lobster catches.

A SCUBA tour guide with a bachelor's in science degree pointed out that current disposal of Sargassum in Mexico is polluting the environment because its leachate contains arsenic. During our literature review on Sargassum, we found that according to Olguín-Maciel et al. (2022, p. 91071) “The leachate generated during the natural decomposition process of Sargassum on beaches or disposal sites represents a high risk of contamination of the Yucatan Peninsula water system due to the high content of arsenic and the presence of potentially toxic metals”.

3.1.2. Economic impacts

On the economic side, all the people interviewed noticed that when there is a lot of sargassum on the coast, the number of tourists that visit the beaches of Mexico and Belize decreases, which affects their economy. Businessmen in the southern area of Quintana Roo report that, from 2015 to date, they have had losses of 50% of their income, compared to years when sargasso did not arrive abundantly to the coast. Other tour operators in Mexico report having 30% less tourism than they had before the arrivals of sargassum.

In Belize, an interviewee informed us that in Turneffe Atoll, and using a scale from 1 to 10 (1 being the least value and 10 the largest value), resorts have had economic losses of 3 due to sargassum arrivals. Moreover, some Belizean tour operators told us that, in times of huge sargassum arrivals, although the tourist is taken to do some alternative activity (for example, barbecue on the beach) or seek for alternative touristic areas to pursue recreational fishing, they notice that tips they receive from tourist (and therefore their income) are less compared to years

when massive sargassum was absent from their working areas. Overall, they commented that the quality of a local marine tour is negatively impacted by the presence of abundant sargassum.

Massive sargassum arrivals have also caused coastal workers and other coastal inhabitants in general, have the burden of other extra expenditures on their working tools and equipment. Interviewees that use outboard motors in their work informed us that their motors get stuck and warm up frequently due to the massive presence of sargassum. As a result, these people have invested more money in motors reparation and replacement than they did in previous years when sargassum did not arrived massively at their working areas. Other extra expenditures were recorded due to frequent maintenance and cleaning of SCUBA equipment, jewelry, and many other electronic appliances including air conditioning and TVs.

3.1.3. Social impacts

In the last decade, atypical influxes of sargassum have caused major disruption in peoples' livelihoods pursued at the Mesoamerican Barrier Reef System (MBRS), as well as in the way they organize themselves to work throughout the year. Most of the social actors interviewed have deployed a wide range of strategies, first of resistance and then of adaptation, as well as innovation to cope with the arrival of sargassum. Some of them have been effective whereas others have not. The main adaptation strategy is that people have organized themselves into working teams to collect sargassum from the beach or from the reef, depending on their nature of their work. This causes that coastal workers have nowadays double working journeys, which is unhealthy, tedious, and tiring. Another adaptation strategy is that the frequency of communication at sea during their trips has increased. This means that when a boat departs from the harbor, it is in close contact with other boats –from the same organization- to ask whether anyone knows of the presence or absence of massive sargassum at the sea. This helps boats' captains in avoiding areas with high sargassum abundance.

With respect to innovation strategies, some interviewees from Mexico stated that to avoid sargassum at the beaches used as embarking sites, they have built special hand-made bridges made of wood which avoid that tourists walk on seaweed beds and therefore, avoid that tourist got allergies or rash because of being in contact with sargassum. One more recorded innovation was a new machine to collect sargassum at the sea, which is like a machine to make corn-flour-made “tortillas”. The latter is linked to a small boat (about 12 feet long) that serves to store the sargassum collected by the machine.

3.1.4. Health impacts

When the sargassum is decomposing, it emits gases that are toxic, such as hydrogen sulfide (H₂S) and methane (CH₄) (Oyesiku and Egunyomi, 2015; Suárez and Martínez-Daranas, 2018), which, when are inhaled by people for relatively long periods of time, cause health problems. In this regard, most interviewees from the two countries told us that working in areas full of sargassum affects some way on their health, varying from mild to serious problems. Mild problems were irritated skin (rash) and headaches whereas other problems were fever, vomiting and serious difficulty to breath. In view of these recorded data, our research team decided that, to have experts’ opinions on this topic and to clarify some doubts, it was necessary to interview Medical Doctors. Our study introduces responses from two Medical Doctors (MD) one from Belize and one from Mexico.

In Belize, the MD provided us with several details on the effects that sargassum has caused on the health of his patients living on the coast, whom he has personally treated. In Mexico, the MD recognized that sargasso’s gases cause pulmonary problems. He recalled the case of a four-year old boy from a rural coastal community that suffered from persistent severe pulmonary problems due to the presence of rotten sargassum nearby the boy’s home. Given these results, our study recorded clinical evidence that sargassum is an issue for the health of people working on the coast affected by sargassum in Belize and Mexico.

We registered that most interviewees are aware that sargassum is an issue for their health. Therefore, those who know this, except tourists, avoid swimming when there is sargassum present at the beach. Also, those who can avoid staying for long at the beach if there is rotten sargassum therein. Some more people, for example, commercial and subsistence fishers, who cannot afford to halt their fishing trips even with huge presence of sargassum, use vinegar for their skin after they walked through beaches full of sargassum.

3.1.5. Cultural impacts

Interviewees informed us that atypical influxes of sargassum prevent local people from doing many of their recreational activities on the beach such as surfing, as well as in general, go for a swim, do outdoor sports, and resting on the beaches of their communities. A couple of people from Mahahual informed us that the celebration of the Carnaval has been cancelled for several years due to massive arrival of sargassum. On one occasion, the Mahahual Carnaval was moved to be celebrated downtown and was carried out on wooden flooring.

3.2. Similarities and differences in the results obtained in Mexico and Belize²

Based on interviewees' information as well as on our own observations, we found that the two studied areas in Mexico and Belize have been similarly impacted in their ecological, social, economic, health and cultural aspects. A summary of key findings is shown in Table 1. Given its importance, we added the aspect of governance to the topic of sargassum to identify which were some similarities and differences among the studied countries.

However, we also found differences in results obtained in Mexico and Belize (Table 2). For instance, some differences have to do with particular knowledge of people

² This heading introduces the results of the following objective: ii) To analyze the similarities and differences in the results obtained in Mexico and Belize in terms of basic ecology and social, economic and cultural aspects.

on specific coastal areas and its flora and fauna. We also found differences in some social and governance aspects.

Table 1. Interviewees' knowledge: a summary of similarities in results obtained in Mexico and Belize related to basic ecology, social, economic, cultural, and governance aspects.

Aspect	Similarity
Ecological	The Mesoamerican barrier reef system from Belize and Mexico, notably fish, the reef and seagrass, is being negatively impacted by atypical influxes of sargassum.
Ecological	Coastal erosion has rocketed and currently, many sand ecosystems contain many rocks.
Ecological	With little and moderate influxes of sargassum, the recreational fishing sector obtains good catches.
Social	Most coastal dwellers' livelihoods have been disrupted due to the atypical influxes of sargassum.
Social	People are interested in knowing what the contents of sargassum are, and whether it is safe to use it or not.
Social	Coastal workers of both countries are willing to help with the sargassum issue; hence, workers' ethnoecological knowledge could inform decision makers and public policy.
Social	People with disrupted livelihoods display an array of coping and adaptive strategies to deal with the massive arrival of this seaweed.
Health	High biomass of rotting sargassum on beaches cause health-related issues to coastal dwellers, ranging from skin allergies to severe pulmonary problems.
Economical	Tourism activities have decreased due to the massive arrival of sargassum off the coasts; hence, coastal entrepreneurs report negative rents.
Economical	The income of most coastal workers, especially tourism service providers, is being negatively impacted.
Cultural	Sport activities, including surfing, have been disrupted at the study area due to sargassum arrivals.
Cultural	Coastal dwellers are not able to safely use beaches for resting or swimming.
Governance	The federal governments oversee sargassum management, which is being addressed at a national level only.

Table 2. Interviewees' knowledge: a summary of differences in results obtained in Mexico and Belize, related to basic ecology and social, economic, cultural, and governance aspects.

Aspect	Differences
Ecological	Recreational fishers in Belize reported that seagrass and therefore the flats fishery is being severely impacted by arrivals of sargassum.
Ecological	SCUBA instructors in Mexico reported that seahorses have disappeared from their known reefs' habitats.
Ecological	Regarding sargassum disposal, many communities in Belize are using this seaweed for landfill. The latter is not happening in Mexico because authorities and local people are aware that a special disposal site needs to be built, which would avoid this seaweed's toxic contents to pollute subterranean waters.
Social	Mexican voices suggest that, given the severity of sargassum impacts, its massive arrivals should be classified as natural disasters, whereas Belizean voices suggest that those arrivals and its severe impacts on coastal inhabitants' health should be regarded as humanitarian crisis.
Governance	Since 2019 the Mexican government has implemented and sustained a federal program to mitigate the arrival of sargassum, whereas since 2016 the Belize's government is managing sargassum primarily through a private-public Committee.
Governance	To mitigate the amount of sargassum arrivals the Mexican government manages the sargassum using fences with buoys at sea as well as sargassum ships and boats to collect this seaweed and transport it to the shore. The government of Belize is not using a mitigation strategy of sargassum arrivals yet; instead, the sargassum arrivals are being collected by both, machinery and coastal workers directly at the communities' shores.

Regarding governance of the sargassum issue, the similarity is that both governments are approaching the sargassum issue at a national level only and not as a trans-boundary resource, despite it is widely known that this seaweed moves throughout the Caribbean like a 'shared resource'.

With respect to differences in governance on this seaweed issue, in Mexico, the federal government, from 2019 to the present, through the Secretary of the Navy, has used a national program of care for massive sargassum arrivals. This program involves the governments of the coastal states and municipalities, especially in the collection of sargassum on the beaches. However, most of the people interviewed are of the opinion that the actions carried out in the federal program for sargassum are not effective in managing the problem, given that the arrival of sargassum continues to occur and the Mexican coastal areas continue to be severely affected by it.

In Belize, several people informed us that, on behalf of the government, a national group called the 'Sargassum Task Force' was formed to address the problem of this seaweed. However, we were told that this operated for some years (2016-2019) and that after that, they have not been called to working meetings. Then, according to the people interviewed, in Belize the sargassum is primarily handled at the level of Village and Town Council to collect it in some touristic areas. However, this does not happen in some communities such as Dangriga or in the Cayes, such as Tobacco Caye, as there is no support for collecting sargassum. In these areas, the people who live and work there have double journey as they are the ones who collect the sargassum during the months of their arrival.

3.3. Recommendations and strategies proposed by the social subjects interviewed³

During our field work in both studied countries, we found much interest in our study. Most of the people who agreed to talk to us had a genuine interest that the problem of massive sargassum arrivals could be addressed more effectively than it has been done in the last decade.

³ This heading introduces the results of the following objective: iii) To write down a final report's section with recommendations and strategies proposed or identified by the social subjects interviewed to address or mitigate the problem of sargassum in the communities of the study area.

This section contains two parts. The first part contains examples of what interviewees are recommending and what strategies they suggest, if any, for the society as a whole (i.e., their government, the scientific community, private and public sectors, NGOs, among others) to improve the management of sargassum. It has some verbatim quotations from interviewees. Its writing style is targeted for people in the studied communities to read and to scholars from the social and humanities fields. The second part is a summary of the key recommendations written in a more Western-science style and is targeted to decision makers and natural resource managers.

3.3.1. Mexico

In the communities studied in Quintana Roo, Mexico, the recommendations proposed by the interviewees to treat the massive arrival of sargassum were diverse. In the following paragraphs, we introduce them grouped in four major themes, namely: a) Informing society about sargassum and its potential effects; b) Local preparation for the arrival of the sargassum; c) Improving the management of the sargassum including mitigation strategies carried out by the Mexican government, and d) Research proposals for the scientific community.

a) Informing society about sargassum and its potential effects

About 70% of the people interviewed in Mexico said that they need information about the massive arrival of sargassum and its implications, especially mentioning that they do not know if it is safe to use sargassum and its potential health effects. A beach club manager, interviewed on the Island of Cozumel, told us:

“More information is needed on this sargassum process. To prevent problems in our health, we should be informed what is contained in sargassum and how it should be handled” (Interview 1).

Similarly, a massage therapist from another beach club in Cozumel told us that she wants to know if sargassum could be crushed and used as fertilizer in plants:

“...Maybe this would dampen the heat of the sun hitting the plants; I would like to know if it is safe to use sargassum or not. I would like more information to raise awareness and understand where sargassum comes from? I have sometimes asked my son, to explain it to me” (Interview 2).

Meanwhile, a tour operator commented something similar:

“My proposal is: give us more information. If we spread what sargassum causes to the population, we would be better informed. Raise public awareness and give talks to be prepared” (Interview 3).

Also, a recreational fisherwoman, when we told her that at the end of our study, first, we would analyze the collected data and that, later, we would introduce the results back to the communities where we obtained the data, she said:

“It is neat that you want to come to give us back the results; to explain to us, to expose us all what you are doing because I believe that, to the people, to the fishers, we lack information” (Interview 30).

In a similar sense of not having a clue about the nature of the huge arrivals of sargassum, another person who is a small-scale merchant in a touristic community, at the beginning of our interview, asked the research team:

“You who know of this, I want to ask you: did that sargassum come alone or was it thrown out?” (Interview 27).

It should be mentioned, apart from the academic literature used by the institutions, that the information related to sargassum that can be reviewed by the Quintana Roo society, is mainly found in the media published on the internet (on Facebook, on the Quintana Roo’s Sargassum Monitoring Network <https://www.facebook.com/RedSargazo/>; and in several electronic newspapers), as well as on the radio. Access to most of the media can be made from coastal cities

with good communications infrastructure, such as Chetumal, Tulum, Puerto Morelos, Playa del Carmen and Cancun or from large hotels and resorts. However, despite being the Mexican tourist destination that receives more tourism, in Quintana Roo there are several communities that provide tourist services but have limited access to the internet. In other words, people in these villages have little access to news about sargassum and what happens daily on the coast of Quintana Roo.

In our experience during the fieldwork of the present study, the communities of Xcalak and Punta Herrero, both located within protected natural areas run by the National Commission of Protected Areas (CONANP), have very limited access to the internet. Also, another of our working areas, the East of the Island of Cozumel, on the part called 'Chen Rio', we found that neither restaurants nor beaches have access to the internet (neither cell phones, nor to use credit cards). In addition, from our previous research work on other projects, we know of other coastal communities with limited internet access, which are Pulticub, Punta Allen (Colonia Rojo Gómez) and Colonia María Elena. Thus, if any authority wanted to keep the coastal population well informed about what's going on with sargassum, people and tourists in these remote communities should have access to up-to-date information either by radio or through a means that ensures frequent arrival of information.

b) Local preparation for the arrivals of sargassum

Most of the people interviewed acknowledged that, from 2011 to date, sargassum has been arriving atypically at the shores of their communities. In this sense, some recommendations to better manage the problem caused by this seaweed have to do with people being prepared for when it arrives to the coast. For example, during his interview, a recreational fisher who is also a fishing tournaments organizer told us:

“There is no excuse for not addressing the sargassum problem well. If we know that sargassum comes every year, why don't we prepare to deal with the problem? (Interview 4).

This recreational fisher and other people interviewed, with a working experience interval between 12 and 50 years on the coast of Quintana Roo (as fishers and as tourist service providers), commented that they know that in this area of the Caribbean, the winds of the East and Southeast, are those who 'bring' the sargassum to the shores, while the so-called 'northern' winds are those who 'take' the sargassum off the shores. These people added that, although with variations, winds from the East and Southeast usually occur from February to August each year. That is, because of their experience and their observations while doing their work on the coast, they have ethnological knowledge related to the period of the year when these winds usually arrive. Moreover, the time in which these winds arrive is also known by experts in meteorology and oceanography (L. Carrillo, pers. com.), some of whom work in the Mexican national meteorological service. Therefore, if this is already known at the level of the Mexican national meteorological system and at the level of the local knowledge of the experienced coastal workers, we, as part of regional institutions should work on developing an action plan, a plan to prevent people from the arrival of sargassum for the months in which the prognosis indicates that they will arrive. Hence, there are two variables that would have to be monitored, the pattern of regional winds and the presence of sargassum before it reaches the coast.

If the Mexican government is able to organize its institutions to deal with the sargassum and in turn, these are able to organize the population of the affected coasts, something similar to the preparation established by Civil Protection for the preparation for the hurricane season in Mexico (Uribe-Martínez et al., 2020), there would be more coordination between the government and the society of the coastal communities affected by this seaweed. Such plans, together with adequate

dissemination, would enhance the responsiveness and adaptability of inhabitants living on the coast affected by sargassum.

c) Improving the management of the sargassum including mitigation strategies carried out by the Mexican government

About 75% of the people interviewed in Quintana Roo told us that they know or have heard about the national strategy and guidelines that the Mexican government has implemented to mitigate the arrival of sargassum to the coasts of Quintana Roo and the Gulf of Mexico (SEMARNAT, 2021). Those who knew of the federal government's seaweed strategy mainly mentioned that they know about the fences with buoys that are put at the sea that try to stop or decrease the arrival of sargassum. Some other people mentioned that they had seen 'sargaceras' boats working and heard about the 'sargacero' ship which operates in coordination with the 'sargaceras'. We asked 30 people this question directly: in your opinion, what do you think of the sargassum care strategy used by the federal government? In their replies, only two people said that the strategy was appropriate; the rest of the people (28) opined that, since they do their work on the coast, they have observed that sometimes the strategy works a little; sometimes it works moderately well and there are times when nothing works. They said it doesn't work because there are years when too much sargassum arrives and it is passed over the fences. Besides, some artisanal fishers informed us that when there are strong winds at Playa del Carmen, the local fences are thrown by these winds on local beaches.

Regarding her proposals to improve the sargassum care strategy, a manager of a dive club commented that the federal government should analyze the array of learning of countries affected by sargassum:

“At the world level, every tourist destination affected [by sargassum] has learned something. They should exchange ideas to see what each has done, what has worked for them” (Interview 11).

During our focus group meeting in Quintana Roo, a cooperative tourism service provider mentioned that it is better for countries in the Caribbean region to join together to approach the sargassum issue:

“I proposed several years ago that why didn’t the countries agree and use international ships to try to stop this sargassum” (Focus group discussion).

For his part, a recreational fisher who oversees organizing fishing tournaments in Quintana Roo, told us that, sometimes, he has sailed up to 100 Km on his boat and there is still sargassum; and that this seaweed has already caused many problems on the coast of Quintana Roo, therefore, he said:

Regarding sargassum: “It is urgent that it be declared as a natural disaster for members of Parliament to address it; it must be treated as a natural disaster and to provide a budget for it” In addition, he said, there must be a control so that that money is not stolen by those who manage it (Interview 4).

Other interviewees commented that although they heard on the radio that several million pesos are spent on the federal sargassum strategy, it seemed to them that sometimes that money is spent for nothing, because sargassum continues to arrive and continues to affect coastal tourism and, in general, the way of life of coastal communities. For this reason, they recommend that to be useful, to be effective, that strategy should be improved. For example, one person who is a small-scale merchant, about her proposal for managing sargassum said:

“I would like to see it put determination, now if that the appropriate dependence, I say, the direct ones that are in charge, or the government, that the problems are in his hands, to pay attention to pick up the sargassum. Think, how will we solve it? ... that we have a clean part [of the beach]; what can be done? Fences? I don’t know what to do but stop this a little” (Interview 27).

For their part, a group of businessmen from southern Quintana Roo clearly know the strategy of the federal government and their leader presented a proposal to improve it to the Governor of Quintana Roo. In their proposal, the businessmen used aerial photographs and maps of the coast of the community of Mahahual and manage to show that the fences that have been placed to mitigate the arrivals of sargassum do not consider the channels of exit of the reef to the sea and that, therefore, do not work. Our research team interviewed the leader of the entrepreneurs, and he told us that he would like the government strategy to consider their proposal so that the money invested on tackling the sargassum issue is better used (Interview 28).

An artisanal fisher also commented us on his hope that the situation with the sargassum problem will improve on the coast and mentioned that sargassum affects them, including that it has caused organized crime to increase:

“The people who live in our communities, we must see them prosperous; we must see that our people are well; and that there is work, and that crime also decreases, because sargassum originates even the increase of crime. That makes those people get easier to local people who are visible and try to extort, steal and a myriad of things, and we are helpless” (Focus group discussion).

d) Research proposals for the scientific community

One aspect that the interviewees are interested in knowing, and therefore that needs to be investigated, is the origin of atypical sargassum influxes. On this recommendation, a recreational fisherwoman, in her recorded interview, told us the following:

“Research is needed (...) we must investigate the reason for the problem”.

“Because all this is a solution –i.e., the sargaceras that collect the sargassum- or is trying to solve a problem, but to solve a problem, we must look for what is generating the problem. And if we don't investigate: 'hey', where does that

seaweed come from? [and] why? Or we already know where it comes from: what can we do to avoid it? Because many solutions can be given; as I say, maybe the right 'sargacera' is not built yet, and we can build it and it will come out and how beautiful! but that is not the issue. No, the point is to see: where does it come from? Is it because of global warming? Or are we littering? Or what are we doing? As human beings, or as a planet or as Mexico; or as, I don't know, in the space where you can place yourself, what can we do to prevent that? (Interview 30).

Some other interviewees told us that other technologies must be tested to treat sargassum. In particular, a tourism business owner told us that he was desperate because he is having huge economic losses due to sargassum arrivals. In addition, he told us that among several local people have organized themselves and are devising some simple technologies-composed of boats and machines like the making of corn tortillas-that can collect the sargassum in the sea, before the alga reaches the coast. At the end of our talk, he showed us a video with his advances in technological innovation collecting sargassum on the coast (Interview 5).

In this sense, two tour operators from the south of Quintana Roo, proposed other innovative ideas to attend the arrival of sargassum.

One of them recommended that, to avoid the economic impact of the coastal infrastructure, why not invest and build a 'smart' fence to contain the arrival of sargassum (Interview 6).

The second operator said he would like someone to be able to invent a turbine that takes the sargassum off before it reaches the coast and causes damage (Interview 7).

Finally, three people (a manager of a diving club, an artisanal fisher and a tourist service provider from a cooperative) acknowledged that sargassum belongs to the sea wherein it causes no harm; for this reason, they were coincident in proposing

that the strategy to take care of it should be that it is not allowed to reach the shores and beaches; that is, that it is contained long before it is able to reach the shore (Interview 11 and Focus group discussion).

3.3.2. Belize

Like what was recorded in Quintana Roo, Mexico, the group of people interviewed in coastal communities in Belize also developed diverse recommendations for their government and the society as a whole, to better manage the problem of sargassum. Thus, in the following paragraphs, we introduce those recommendations similarly grouped in four major themes, which are: a) Informing society about sargassum and its potential effects; b) Preparation for the arrival of the sargassum; c) Improving the management of the sargassum including mitigation strategies carried out by the Belizean government, and d) Research proposals for the scientific community.

a) Informing society about sargassum and its potential effects

During our field work, we watched more workers collecting sargassum in Belize than in Mexico. All the people we saw working on collecting the seaweed had no protective clothing. In order to know if these people have any health problems, we spoke to several workers. One of them was an employee of the village council of Caye Caulker.

The worker used a trench with which he was picking up the brown, rotting sargassum on the beach. We asked him if he had noticed if his work with sargassum caused any health problems or not. He responded by saying 'yes'. He added that since he works with the sargassum he has headaches frequently and sometimes gives him a fever. We asked him if he had visited the medical doctor to take care of his troubles and he answered 'no' (that he hadn't do that) (Open interview 6).

The above example shows that this worker does not know that sargassum emits gases that are toxic, such as hydrogen sulfide (H₂S) and methane (CH₄) (Oyesiku and Egunyomi, 2015; Suárez and Martínez-Daranas, 2018), which, when inhaled for relatively long periods of time, cause health problems, including headaches.

In this sense, the Medical Doctor interviewed in Belize told us that little is known about the content and health effects of sargassum. He said there is lack of awareness. Particularly, his comment was as follows:

“Sargassum, apart from causing health problems, also caused a panic problem. For example, the problem of sargassum was very evident: here in Caye Caulker the fish began to die; then, many people began to see fish floating on the seashore (some of them, already dead and others still moving). Some people, out of ignorance or curiosity, grabbed it and consumed that fish”. The MD added: then those people started having gastrointestinal problems; they got diarrhea. But here is known the other problem that is the ciguatera; so I attended patients who were very frightened, since they did not know if their gastrointestinal problems were by consuming the fish they collected from among the sargasso or by ciguatera problems, and this caused, at one time, stopped buying and selling fish in Caye Caulker (Open interview 8).

In Hopkins, some people told us that they used sargassum to grow vegetables and in Caye Ambergris and Caye Caulker told us that they use it for landfill.

In view of the foregoing, we consider that it is necessary for Belizean society from the coast to know more in detail the content of sargassum and the toxicity of the gases it emits when it is decomposing. If people are informed about it, that would avoid or diminish the likelihood for them having health-related problems.

b) Local preparation for the arrival of the sargassum

During the talks and interviews in Belize, the members of our research team paraphrased the questions in our study. So, when we interviewed the Medical Doctor, we asked him: If it were in your hands, what would you propose to address the sargassum problem in Belize? What would you pay attention to?

“Well, first of all, what I would try to do is involve the Ministry of Environment and my thinking on that would be simply: prevent. Try to make [and place] a barrier so that [sargassum] does not reach our beaches. In doing so, it will not come, or it will be less, and the effect it will have on humans, is much less. Then, the management of all complications would be much better; the economic expenditure of the country would be much less, because it is easier to prevent. Sargassum has been addressed in a reactive manner; some people prefer preventive work; we must prevent” (Open interview 8).

Like what happened in Mexico, in Belize, artisanal and recreational fishers interviewed mentioned about the relationship between the arrival of winds from the East and Southeast and the arrival of sargassum to the coast. These people were knowledgeable about ‘northern’ winds are those that ‘take’ the sargassum off the shores. They acknowledged that winds from the East and Southeast usually occur roughly from February to August each year. Given this people’s knowledge held among fishers, we suggest that the Belizean government could also devise a preventive plan to deal with the arrival of sargassum on an annual basis. We mean that Belizean governmental institutions could organize the population of the affected coasts, something similar to the preparation established by Civil Protection for the preparation for the hurricane season.

c) Improving the management of the sargassum including mitigation strategies carried out by the Belizean government

Most of the people interviewed acknowledged that they have between 7 and 10 years of coping with the problem of sargassum (depending on when their working

areas were flooded with sargassum on the coast). With these years of experience coping with this problem, they recommend the government of their country to make decisions so that this problem is better addressed. A professional expert told us:

“I don’t think sargassum should come as a surprise now. You wake up in the morning and the sargassum is there: no! The problem is there, and we have recognized it as a problem, and we must already have an idea of how we are going to deal with it. Now everyone has access to information. Governments can see how sargassum is in the Caribbean, how it is in the Yucatan Peninsula; that gives them the opportunity to implement those mitigation plans and other activities” (Open interview 2).

On the other hand, a tour operator, including fly fishing, who has 23 years of work in the tourism sector opined that, the whole problem of sargassum care should not be handled only to benefit the tourism industry. He said, that must be taken care of to improve the lives of Belizeans. His speech put it in the following terms:

“I think that for too long, how we sell Belize in the touristic industry, as a country (...), what I encourage a lot is to sell [it] a little broader, when it comes to the sargasso and any other matter, stop using the word just “tourist”: [use] the wellbeing of the Belizean people. [W]hen you have a meeting and say: men, the touristic industry has been impacted tremendously by sargasso, we want to bring out a team for a clean-up campaign... bla, bla, bla. They just heard that you restrict yourself: [they will respond] I am nothing to do with tourist; I don’t do tourist, I don’t. I have my [own] business. But indirectly, every single person in Belize benefit indirectly from tourist; some a lot directly. But my point now, you sell yourself short, because you are cleaning “this” up for tourist; that is a big lie. It is obvious, yes, but it’s a big lie. My point, I will try to get it quick: the people that don’t work tourist won’t come out and help because you are cleaning up for tourist. And then I go to reverse to my wife, she is dying from it, so, the tourist only spends one week [in Belize], it [the sargasso] mess up their lungs a little and they are gone; the

Belizean people is the one that is dying. In the long term, you don't know what is going to happen.

Just like crime, just like anything else. If the crime don't [doesn't] get better, it is for Belizeans the crime needs to get better for (...). And that tourist is nice, most often, tourist ... that is why there is your bread in your table; but you limit yourself when you say you are doing this for tourist; we are doing this for the Belizean, to enhance the Belizean life" (Open interview 16).

In particular, about his proposals to manage sargassum, this tour operator commented that, in his opinion, what happens with sargassum should be recognized as a humanitarian crisis:

"It is a humanitarian crisis; is the trimness up for the Belizean people to step up and be afford; and the biggest point in there is for Belizean to feel more ownership. (...) because yes, we have to sell, we got to bring investors, but tell me Miss "Researcher", why should a normal person care about this beach, so beautiful, and they aren't making anything from it. They [the people] don't own anything, they can't even get a job in it: "why should I care about that! what are you talking about?" (Open interview 16).

During another interview, a recreational fisher, with nearly 50 years of experience working off the coast of Belize, told us:

"The problem of sargassum already surpassed us in terms of how to stop it". In the sargassum issue: "For me, there is no science; they don't pay attention to it. Because there are quite a few young people who have a career in marine biology, right?" There is no science; there is no coalition among Caribbean countries, which says: we are going to find a harmonization of science to study this grass. Because I didn't hear there was a sargassum summit in the Belize area yet. That Mexico, the Cayman Islands, the Bahamas, Jamaica, all the Caribbean countries, including Venezuela, say: we're going to hold a summit, we're going to look for it, we're

going to look for a science; we're going to look for a solution as to why. Where the sargassum comes from? No one has looked for where the root [of sargassum issue] is. [Is] in the Caribbean?, in the Atlantic? No one has found out the root of the problem as to say I'm going to grab it from here before it reaches the Atlantic coast. Because countries must come together and decide that they are going to the United Nations and ask that they support us. There is no such thing; there is no unification; then, every country that is affected by sargassum has a problem (Open interview 1).

The Professional expert we interviewed suggests something similar: he commented that it has to work at the regional level, at the Caribbean level, his opinion expressed it as follows:

"I don't think we understand the extent of the problem yet. This problem could become more serious, we do not know; and we are not clear either what is causing the problem, but it is affecting the entire region. It is not a localized problem; it is a regional problem that has to be addressed in that way; there is no other solution". (Open interview 2).

Particularly, this expert said:

Belize could address the sargasso problem at CARICOM level [Caribbean Community – caricom.org]; there is a proposal in place to do that. Even SICA [Sistema de la Integracion Centroamericana, sica.int]. Countries should not go to a meeting individually -Belize or Mexico, they need to plan on a regional basis". (Open interview 2).

Our research team searched for other associations similar to CARICOM and SICA and found the Association of Caribbean States (ACS/ACS) which has 25 member countries, two of which are Belize and Mexico. This is another option for regional work. Moreover, this organization is already recognizing that sargassum is an urgent problem to address in the region:

ACS Secretary General Rodolfo Sabonge addressed the urgent problem of Sargasso in a speech to the countries of the region: "This crisis represents a significant threat to our economic, social and cultural development, with adverse effects mainly on tourism activities, fisheries and the preservation of the sustainability of our marine and coastal ecosystems and the biodiversity they harbour," said Mr. Sabonge (ACS, 2023).

Similarly, the Medical Doctor interviewed told us that he has also been reading the news about possible factors that may be causing the biomass of sargassum to grow a lot in the sea and said:

"I believe that if they [the countries] come together regionally, we will have a much greater voice to counter the problem. Or even tell developed countries, about their industries and agrochemicals coming to sea 'hey what you're doing also affects other people', and with that you make a global awareness and maybe that helps (...)" (Open interview 8).

In Belizean remote communities, particularly in Tobacco Caye, three interviewees issued the following recommendations for sargassum management:

A lodge manager told us:

Sargassum is dangerous and unhealthy; two days after its arrival there are many flies. Government of Belize can help by coming around and seeing the impact in the tourism industry and they can also remove the sargassum out at sea before it reaches the shore and at Tobacco Caye (Open interview 15).

Another person who works as a tourist guide said:

2022 Easter was "bad bad", all week we had sargassum and it was an all-day effort to try to clean it; we would put it on the channel and the current would take it away. Some tourists are afraid to get stung and they are hesitant to get in or do not enter

at all. It would be good to have the resources to facilitate the removal and disposal of sargassum from Tobacco Caye, perhaps a boat to transport it to Dangriga. The government of Belize has never provided any help not from Belize Tourism Board or even the Department of the Environment. They haven't even asked about the problem. We don't bother asking for help because we know we won't get any assistance (Open interview 16).

Similarly, a person who works in the maintenance of the lodge on this Caye told us: When we enter to sail and there is a lot of sargassum, this one enters in the engines, which are locked and at every moment we have to raise the engine to remove the sargassum and continue sailing: it is a lot! The Town Council needs to come out to see what is going on (Open interview 17).

Other proposals recommended by the people of Belize were that sargassum should be used. For example, an emergency rescuer working in the tourism sector expressed it as follows:

About sargassum: "something positive is that we could find what are we going to do with it; use it, instead of just removing it from one site, and throwing it, still as a problem, elsewhere".

"Our association would participate in whatever program could be positive with removal and even as far as creation of products out of sargassum because we are affected directly. We deal every day with tourists that ask, What is sargassum? Where does it come from? Why this smell so bad? and we have to be answering these questions on a daily basis" (Open interview 7).

Several initiatives have already been made on possible uses of this seaweed, for example, in an interview we were told the following:

"When we were in the quarantine (covid), we wanted to make a farm. We wanted to plant vegetables and since sargassum was a problem, we wanted to know how we could use sargassum as fertilizer? So, we had already contacted the Ministry of

Agriculture; they found it very interesting. And not only that, the gases emitted [by sargassum] could be used to produce energy and in this way, we could irrigate plants. But obviously, it was not possible for economic reasons; and well, in that step we stopped” (Open interview 8).

d) Research proposals for the scientific community

Several research proposals for the academy have to do with evaluating the impacts that sargassum causes on the ecosystems of the Mesoamerican Barrier Reef System (MBRS), from the dune, erosion of beaches, mangroves, seagrass, as well as the reef and its associated biotic communities. Although there have been several isolated or *ad hoc* investigations on various topics in the MBRS, to date, there is no macro-level evaluation of this system.

In this regard, the Belizean Professional expert we interviewed was a member of the Sargassum Task Force. He told us about his comprehensive vision of some impacts of the atypical arrival of sargassum that he has observed in the reef and reef lagoon of Caye Ambergris. He told us that the entire coastal-marine ecosystem of Belize is being severely affected by this seaweed and that this is not being evaluated by the scientific community, by NGOs or by governments. He referred to this as an impact on the entire MBRS and in particular emphasized seagrass (*Thalassia* spp. and associated species). Specifically, he mentioned that, in several areas of the eastern part of Caye Ambergris, there is no longer *Thalassia* spp. and that where it exists, it has lost its function as a breeding ground for juveniles of various species. He added that, he imagines, if this effect has taken place in Caye Ambergris, it is also occurring throughout the MBRS. If this is the case, this will undoubtedly have an impact on the region’s fisheries in the short and long term:

“How much seagrass have we lost? It should be mapped, and it should be evaluated what would be its impact on fisheries. Not even the Department of Fisheries has begun to quantify the extent of the damage”. (Open interview 2).

Similarly, two fishers, with over 50 years of experience working at sea, told us that they have seen the disappearance of seagrass from several areas off the coast of Belize. One, it was a recreational fisher who mentioned that the grass has disappeared from the eastern part of Ambergris Caye (Open interview 1).

The second fisher works in the lobster fishery, but he is also a small trader in Caye Caulker. Nevertheless, although worried, he told us that he is optimistic because he believes that the sea has a lot of energy and that it will recover from the arrival of sargassum (Open interview 6).

To verify what studies have been carried out on the macro-level effects of sargassum on the MBRS and its 65 protected natural areas, particularly on seagrass, our research team, reviewed, from February to June 2023, several platforms of non-governmental organizations working on the MBRS, but for reasons of space, we now list only the following two: i) the Mesoamerican Reef Restoration Network (coralmar.org): on this website we did not find studies or projects related to any issue of the effects of sargassum on corals; and among the threats to MAR that they list on their website (<https://coralmar.org/amenazas-de-los-arrecifes-de-coral/>), we did not find the atypical arrivals of sargassum taken into account, nor did we find any data related to the disappearance or deterioration of the MBRS' seagrass; ii) the Healthy Reefs (healthyreefs.org), where, in 2022, the Health Condition Index of the MBRS' decreased compared to last year; and when discussing the factors that may be impacting the health of the MBRS, this organization did not address the problem of the impacts of sargassum on the reef nor mention the deterioration of seagrass areas, but only discuss the problem of health deterioration taking into account other factors, mainly coastal development (see McField et al., 2022).

To close this section, we have the views of two Belizean officials. One of the Authorities interviewed is from San Pedro Town Council and told us the following:

On sargassum, “how to get it out and where to put it is what impacts us the most”. She said the budget to remove it comes from the Sargassum Task Force. Of the impacts she has observed is that the sargasso has severely impacted the areas of seagrass. She added that they have plans to take advantage of sargasso; for example, she said, “Taiwan is interested in sargasso, but we don’t have the equipment to take advantage of it” (Open interview 4).

Also, the Caye Caulker Authority told us how they handle the problem with this seaweed:

Regarding sargassum management: “We are dealing with the crisis. Our main problem is the disposal of sargassum. Land is limited in this island; if land got saturated of sargassum, what are we going to do with the sargassum disposal?” In addition, the Authority of Caye Caulker is interested in learning other management techniques for sargassum; she said: “We need to innovate on sargassum disposal”. (Open interview 9).

According to the problems that these two authorities face in collecting the sargassum, the challenge for the scientific community is to research on innovation issues for a final and safe disposal of the sargassum.

3.3.3. Summary of recommendations and strategies proposed by the social subjects interviewed

Given that our research team is interested that our study’s results could be useful to the governments of Belize and Mexico who oversee managing the sargassum issue at a national level, the latter section’s results were summarized and organized on a more Western-science style targeted to decision makers and natural resource managers. In this regard, we consider that the recommendations suggested by interviewees (as well as their ethnoecological knowledge) could serve as input, say for designing any integral program on sargassum including

mitigation plans. To move forward, here, we suggest that it is going to be an integral program for sargassum management which objective is to improve the management of sargassum off the coasts of each country (i.e., Mexico and Belize). For instance, this program could consider one or more recommendations posed by interviewees and will have a goal, a strategy to follow, and an expected outcome (Table 3).

Table 3. Inputs to an integral program for sargassum management: Key recommendations and strategies proposed by the social subjects interviewed aimed at improving the management of sargassum in Mexico and Belize.

Objective	Improve the management of sargassum off the coasts of Mexico and Belize		
Recommendation	Goal	Strategy (pointing out institutions that could work on each recommendation)	Expected outcome
Community groups and entrepreneurs who pursue livelihoods on coastal activities, such as fishing and tourism, consider that they do have something to say about the sargassum issue	Innovate on governance about the sargassum issue: use interactive governance by first addressing it at local levels or at communities most impacted (based on this study's ranking)	i) organize a Forum to identify who the potential allies (stakeholders) are to address the sargassum issue (include people directly impacted by decomposing sargassum), ii) conduct regular meetings prior and post sargassum arrivals to plan and evaluate the impact yearly, and iii) write down a policy based on the results obtained from points i) and ii)	All actors involved in the governance of coastal territories 'got the picture right' on the complex sargassum issue. Therefore, all social actors are better prepared to cope with this marine seaweed
Coastal communities need information on the massive arrival of sargassum and its implications, notably if this seaweed is safe for people to use and what its potential health effects are	Informing society about sargassum and its potential effects on socio-environmental systems and human health	NGOs and grassroots organizations, public and private scholarly institutions (e.g., University of Belize, BTT, ECOSUR), and governmental authorities of the two countries	Improve people's knowledge on sargassum, creating awareness on its potential effects on socio-environmental systems and human health
If during the last 10 years sargassum arrivals are brought by East and South-East winds on an annual basis, coastal inhabitants need to locally be prepared to better cope with these arrivals	Change the management of sargassum from being reactive to preventive including local preparation of people for the arrivals of sargassum	Governmental authorities of the two countries, in interaction with private and public actors, would design a preparation plan for sargassum arrivals -similar to preparation plans for hurricane arrivals	Improve people's preparation to better cope with sargassum arrivals diminishing the risks of socio-environmental and health damage
Working on sargassum management at a country level doesn't work as the dispersal of the seaweed is carried out by the ocean currents and winds at the Caribbean region level	To have more efficient and effective use of economic resources on sargassum management	Governmental authorities will work either at a bi-national level or at the Caribbean States-level, as appropriate, on a wider Caribbean sargassum management plan	Money invested on sargassum management was optimized, resulting in coastal communities having much less seaweed arrivals

<p>All what is currently doing on sargassum management is tackling the impacts of sargassum only, the scientific community needs to find out the causes of the sargassum bloom</p>	<p>Invest in medium to long-term research at the Atlantic's interface atmosphere-ocean to find out what factors are causing the sargassum bloom</p>	<p>The scientific community will work at a Caribbean States-level, as appropriate, on a medium to long-term wider Caribbean sargassum research project</p>	<p>Contribute to science and the well-being of coastal communities in finding out what factors are causing the sargassum bloom</p>
<p>Given that current disposal of sargassum is an issue for the social and ecological sides, there is a need in innovating on sargassum disposal</p>	<p>Invest in short-term research projects on appropriate sargassum disposal</p>	<p>The scientific community will work in coordinated short-term research projects on appropriate sargassum disposal</p>	<p>Contribute to sustainability of the ocean and the well-being of coastal communities in finding out a technique for the proper disposal of sargassum</p>

4. Concluding remarks

This report contains the results of the socio-environmental analysis of the impact of the massive arrival of Sargassum off the coasts of Mexico and Belize. The problem of sargassum is complex and wicked and must be analyzed from a multidimensional perspective, using transdisciplinary approaches with participation of experts from several branches of knowledge as well considering local knowledge from coastal workers.

Our results show that local and scientific knowledge about the atypical arrival of the sargassum are complementary to understand the impacts of this seaweed from several perspectives, both on the social side and the marine environment.

Although the use of people's knowledge on the sargassum issue had already been suggested by Rosellón-Drucker et al. (2022b), this knowledge has not been tapped, either in Mexico or Belize yet. From 2011 to date, massive sargassum arrivals caused ecological impacts on the marine environment and the Mesoamerican Barrier Reef System (MBRS), and on people who pursue livelihoods on their coastal territories. Most often, these impacts are interrelated since ecological impacts of sargassum on the marine environment have consequences for coastal inhabitants on their social, economic, health and cultural aspects.

Large, atypical influxes of sargassum result in death of many marine species both, flora and fauna, notably seagrass, the reef and fish. In turn, this ecological impact negatively affects recreational fishing and commercial and subsistence fishing on community docks. Thus, fish have been scarce in the study area with negative consequences to the food security of subsistence and commercial fishers and their families.

On the economic side, when there are massive sargassum arrivals the number of tourists decreases in both Mexico and Belize; therefore, interviewees from all the sectors reported economic losses in their income, their tips, and due to extra

expenditures they have related to working equipment and electronic appliances maintenance and replacement.

On the social side, massive seaweed arrivals have caused changes in the social organization of coastal livelihoods. Most interviewees have nowadays double working journeys, their normal work and the work of collecting sargassum from their working areas (i.e., beach, reef), which is unhealthy, tedious, and tiring. The majority of the social actors interviewed have deployed a wide range of strategies, first of resistance and then of adaptation, as well as innovation to cope with the arrival of sargassum.

Regarding health, most interviewees from the two countries told us that working in areas full of sargassum affects their health, varying from mild to serious problems. Due to the gases of hydrogen sulfide (H₂S) and methane (CH₄) that decomposing sargassum emits coastal workers who collect decaying sargassum need to use protective clothing during their working schedules. Moreover, many interviewees don't know what the contents of sargassum are and whether it is safe to use it or not. Therefore, they want to be better informed about the potential sargassum effects on their health.

In addition, several people opinionated that the sargasso belongs to the sea and should remain there where it causes no harm. In other words, it should be prevented from reaching the beaches, where it causes a lot of damage. They also mentioned that prevention of sargassum arrival would be a better strategy for coastal workers and, in general, for all inhabitants of the coasts affected by it. Preventive rather than reactive action would partially reduce the costs of management strategies, both for the governments of Mexico and Belize, and for the public and private sectors. Moreover, some interviewees suggested that the scientific community should investigate further to find out what are the factors that are causing the huge sargassum bloom that reaches the coasts of our study area.

They commented that they want to know what the root is, instead of only working on the solution of the current problem on sargassum.

The current management strategy of the sargassum in Mexico has to do with mitigating its arrival at the coast and, that sargasso that reaches the beaches, is collected. In Belize, we find that, the management strategy is just to harvest the sargassum that reaches its coasts and its islands. In both countries, there are no sites specially prepared for a safe final disposal of this seaweed. For this reason, by collecting the sargassum and taking it elsewhere, the impacts it causes are not solved, given that it contains arsenic and other toxic elements, so that, wherever it is thrown, its leachates continue causing pollution to the environment. In both Mexico and Belize, there are recommendations from people that the sargasso problem should be recognized as a natural disaster. Furthermore, in Belize, one interviewee suggested that it be considered a humanitarian crisis.

Particularly for Belize and Mexico (as well as Guatemala and Honduras), the shared resource of the Mesoamerican Barrier Reef System (MBRS) will not be properly conserved, and its environmental services will continue to deteriorate because the sargassum mitigation efforts of each of these countries are only at the national level. The MBRS' ecosystem that was most recognized as deteriorated by the interviewees was the seagrass. One professional expert mentioned that this impact must be evaluated as he foresees that there will be negative impacts on fisheries (artisanal and recreational) in the short and long term.

In Mexico, although the federal government has made efforts and invested money in the sargassum strategy, there are opinions from the public at home and abroad, particularly those living in coastal communities affected by this seaweed, that, to date, the results of this strategy have not been effective. To move forward in mitigating the arrival of this seaweed, there is a need to create a pro-positive dialogue between the government of each country and the people who work, face and cope with the arrival of this seaweed on a daily basis, i.e., people who make a

living from fishing and tourism – the private sector and social organizations such as cooperatives, as well as coastal dwellers in general. This is relevant because, as recognized by Medical Doctors we interviewed: at the study area sargassum is also a health problem.

Therefore, it would be desirable that the strategy of care for sargassum be discussed and re-planned in the two countries studied. During this exercise, the governments of these countries could support their decisions on sargassum taking into account the accumulated experiences and knowledge of coastal workers which were put in the form of recommendations in this study (see Table 3). In other words, governments and other stakeholders should use interactive governance.

Furthermore, our expert assessment of the impacts of sargasso agrees with what was expressed by several interviewees: the government of each country affected by the atypical arrival of sargasso will not be able to solve or mitigate this problem by working alone. If a government decides to work alone, it seems that the only strategy it would be to use an approach using small patches for a larger problem (i.e., 'a band-aid approach') since sargassum does not remain at the national level, but, as with other shared resources in the Caribbean, it transcends political borders. In this regard, interviewees suggested that multinational collaborative work on sargassum is needed throughout the Caribbean region. For instance, Mexico and Belize could collaborate to discuss and implement a binational strategy for sargassum care. We are sure that academia, NGOs and societies in Mexico and Belize would welcome and support such initiatives. But ideally, interviewees proposed that the multinational dialogue be at the summit level of all Caribbean States. There are already some initiatives under way through the Association of Caribbean States (ACS, 2023), among others, which should be built upon. Finally, the monitoring of sargassum arrivals and its impacts need to be further researched in the social and environmental realms. Ideally, a multinational research team at the Caribbean-level should be formed.

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