

Seaweed blooms in paradise: Ecological reflexivity, governance and the *Sargassum* crisis in the Mexican Caribbean

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ABSTRACT

Seaweed blooms pose a compelling governance challenge caused by the new environments of the Anthropocene. Along the Quintana Roo coastline, nestled in the heart of the Caribbean, the onset of extensive *Sargassum* infestations began in late 2014, posing a formidable environmental management dilemma for state and federal authorities. This study describes the institutional responses elicited by the *Sargassum* influx on Mexico's Caribbean shoreline, particularly focusing on Cancún and the Riviera Maya. It proposes ecological reflexivity as a promising governance principle for institutions faced with increasingly complex and unforeseeable circumstances, such as the massive arrivals of *Sargassum*. Based on a comprehensive analysis of national press reports, active participation in forums and seminars, and in-depth interviews, our research identifies three distinct governance phases. We explore these phases considering the concept of ecological reflexivity. Our findings make a strong case for acknowledging institutional errors and shortcomings as an indispensable aspect of formulating effective strategies to combat unexpected and unfamiliar phenomena such as seaweed blooms. Moreover, governance strategies for dealing with *Sargassum* in Quintana Roo should not only consider responding to human interests and sustaining the tourist industry. Instead, they should encompass an approach that considers the interplay between human and non-human components within the socio-ecological system.

Keywords: Macroalgae, Anthropocene, Non-human, Institutions, Beachcast

INTRODUCTION

Phenomena such as extreme weather events, rising sea levels, and the proliferation of invasive species are hallmarks of the Anthropocene era. These occurrences, marked by their unpredictability,

increasing frequency, and devastating impacts, present formidable political and ecological challenges to established human institutions (Head and Atchinson, 2015; Dryzek and Pickering, 2019). In Western liberal democracies, environmental governance frameworks were conceived during the comparatively stable and predictable environmental conditions of the Holocene. However, they are now confronted with rapidly evolving socio-ecological systems characterized by substantial uncertainty (Moon et al., 2017, Dryzek and Pickering, 2019;

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Pickering, 2019). In light of Dryzek's (2006) assertion that Holocene institutions may inadvertently accelerate climate change, species extinction, and destabilize the Earth's systems, a pressing question arises: What environmental governance principles and arrangements are needed to navigate and mitigate these distressing trends?

Given humanity's transformative impact on the planet's biophysical dynamics, it is imperative that environmental policies transcend the traditional approach of merely responding to natural forces. Instead, they must acknowledge and take into account our significant influence on these dynamics. As such, the institutions tasked with shaping environmental policies must possess the ability to reevaluate and adapt not only their performance, but also their underlying values and ecological footprint (Dryzek and Pickering, 2019; Biermman, 2021). Dryzek and Pickering (2019) call this critical capacity *ecological reflexivity* — a central element for building effective governance systems in unpredictable socio-ecological environments. Ecological reflexivity makes it easier for institutions to avoid path dependency, thereby fostering flexibility and responsiveness to emerging challenges and opportunities.

Algal blooms have become a major governance challenge in the context of the evolution of environments during the Anthropocene. The overgrowth of some algal species results in the formation of extensive rafts that reach tens or even hundreds of kilometers along the coasts of the Caribbean, the Gulf of Mexico, the Mediterranean, and China, among other places (Charlier et al., 2007; Smetacek and Zingone, 2013). Over the past two decades, these blooms have become more frequent and intense. They are mainly attributed to two genera: *Ulva* and *Sargassum*, both cosmopolitan algae whose growth responds primarily to the availability of nutrients (Smetacek and Zingone, 2013). The accumulation of tons of algae along beaches and coastal waters for several months of the year hinders beach activities, disrupts small-scale fishing, and poses a serious threat to marine species such as corals, fish, and sea turtles. If left unaddressed, the rotting algae release toxic gasses such as hydrogen sulfide, creating an unpleasant odor, and leachates

with negative impacts on coastal ecosystems and, potentially, human health (Smetacek and Zingone, 2013; de Lanlay et al., 2022).

Since 2011, Caribbean countries have seen massive arrivals of *Sargassum* (Gower et al., 2013). In the Mexican Caribbean, landings on the coast of the state of Quintana Roo began in late 2014 (Rodríguez-Martínez et al., 2016; van Tussenbroek et al., 2017). This challenge has intensified significantly, with massive landings occurring annually for five to seven months since 2018 (Rodríguez-Martínez et al., 2022). Quintana Roo is home to globally important beach tourist sites along the Riviera Maya. In 2022, almost 20 million tourists visited the state, which captured 43.4% of Mexico's tourism revenue (SEDETUR, 2023). *Sargassum* landings on the region's coastlines represent a serious environmental management challenge for state and federal officials (Rodríguez-Martínez et al., 2016; Novedades de Quintana Roo, 2018). Some research has analyzed the causes and ecological impacts of *Sargassum's* arrival on Mexico's Caribbean shores, including the algae's chemical composition and potential uses (van Tussenbroek et al., 2017; Rodríguez-Martínez et al., 2019; 2020; Chávez et al., 2020; Rosellón Druker et al., 2022). Nevertheless, except for the recent state-of-the-art analysis conducted by Rosellón Druker and colleagues (2022), there is still a notable gap in the literature when it comes to the governance and emergent institutional frameworks in Mexico for the management and disposal of *Sargassum*.

The primary objective of this paper is to provide an in-depth description of the institutional responses to the arrival of *Sargassum* on Mexico's Caribbean coast, with a focus on Cancún and the Riviera Maya. Furthermore, the article seeks to explore the concept of ecological reflexivity, proposing it as a promising governance principle that is particularly relevant to the institutions facing the increasingly complex and unpredictable challenges posed by *Sargassum* blooms. To address these goals effectively, we pose the following questions: 1) What specific measures and organizational strategies have been implemented along the Riviera Maya to address the issue of *Sargassum* landings, and 2) What incentives and obstacles currently exist

to move towards governance schemes that embrace and integrate the principle of ecological reflexivity?

We begin this paper by outlining Dryzek and Pickering's (2019) analysis of environmental governance during the Holocene. We present their argument in favor of ecological reflexivity and elucidate why it stands as a more appropriate approach for addressing the novel challenges of the Anthropocene epoch. We then present an overview of the study region, as well as some key features of *Sargassum* and its movement towards the Caribbean. The results section examines the progression of *Sargassum* management in Quintana Roo from 2015 to 2022. Here, we highlight institutional arrangements and governance frameworks and evaluate their efficacy in mitigating the predicament posed by the massive influx of *Sargassum*. We also indicate the principles that guided governance responses over time. In the discussion and conclusion, we return to the concept of ecological reflexivity to discuss our findings and present some concluding reflections.

GOVERNANCE AND ECOLOGICAL REFLEXIVITY

Environmental governance refers to the set of regulatory processes, mechanisms, and forms of organization with which political actors, such as the state, entrepreneurs, NGOs, communities, and scientists, among others, can influence, direct, and coordinate decisions on the interaction with and management of the environment (Lemos and Agrawal, 2006; Moon et al., 2017). Some characteristics of effective democratic governance structures are decentralization, accountability, deliberation in decision-making, and, more recently, flexibility in the face of changing socio-ecological systems (Head and Atchinson, 2015; Moon et al., 2017; Feindt and Weinland 2018).

The instability generated by the ecologies of the Anthropocene compels the need for a fresh analysis of environmental governance models. As Dryzek and Pickering (2019) suggest, existing environmental governance models were forged within the more stable and predictable conditions of the Holocene. Throughout the Holocene, local environmental governance mainly revolved around devising mechanisms to prevent the overexploitation of resources (Ostrom, 1990;

Dryzek and Pickering, 2019). The post-World War II era witnessed the profound "great acceleration" of fossil-fueled capitalism, along with the rise of environmental concerns in the 1970s. These factors compelled state institutions to address natural resource degradation and environmental protection more thoroughly (Dobson, 1995; Dryzek, 2016; McNeill and Engelke, 2014). Nonetheless, as Dryzek (2016) argues, liberal societies have inadvertently perpetuated an "implicit ecological contract" characterized by dominant relationships with the non-human world, primarily for the benefit of humans. Similarly, the biophysical environment has often been marginalized, seen merely as a backdrop to human affairs. Hence, Holocene governance institutions tend to downplay ecological concerns, as evidenced by the framing of negative environmental impacts as externalities (Pickering, 2018). Ultimately, state actors in capitalist societies have predominantly prioritized economic growth, security, and social welfare (Dryzek, 2016).

Existing governance frameworks, such as adaptive governance, resilience, and social learning, were designed to cultivate the capacity to adapt and respond effectively to changing socio-ecological conditions (Pickering, 2018). And yet, as Pickering (2018) argues, these models ultimately maintain "the same overall identity and functions" of existing institutions. For this reason, Dryzek and Pickering (2019) suggest that Holocene governance "decouples human institutions from the Earth system by embodying feedback mechanisms that systematically repress information about the condition of the Earth system and systematically prioritize narrowly economic concerns." For these reasons, conventional governance models prove inadequate for addressing how established institutions contribute to increasing instability in Earth systems, and also how this instability affects their ability to govern effectively (Dryzek and Pickering, 2019).

To overcome institutional rigidity and incorporate the dynamics of socio-ecological systems as fundamental variables in environmental governance, Dryzek and Pickering (2019) propose the concept of ecological reflexivity. This term is

defined as “the capacity of an entity (e.g., an agent, structure, or process) to recognize its impacts on socio-ecological systems and vice-versa, to rethink its core values and practices in this light, and to respond accordingly by transforming its values and practices” (Pickering, 2018).

Ecological reflexivity encompasses three components, which can be translated into observable signs of reflexivity for political analysis: recognition, reflection, and response (Dryzek and Pickering, 2019). Recognition consists of noticing the physical and discursive impacts of institutional arrangements on socio-ecological systems, identifying what the natural world and the actions of non-human entities communicate to us, and predicting future effects on the socio-ecological system. Reflection includes the learning processes that derive from success and failure, the reconsideration of objectives and the means to achieve them, and the imagination of possible organizational and action alternatives. Finally, response refers to the process of rearticulating and reconfiguring the principles, values, functions, and practices of the governance system (Pickering, 2018).

Reflexivity is facilitated by: 1) deliberative processes involving actors from different levels of governance, with different knowledge, experiences, and the capacity to seriously consider alternatives for understanding the problem, along with multiple approaches to potential solutions; and 2) the ability to review cognitive and normative beliefs and reconsider institutional arrangements and practices, as well as the values and assumptions that underpin them (Dryzek and Pickering, 2018; Feindt and Weinland, 2018). Including ecological reflexivity in governance schemes means understanding and managing the links between institutional change and socio-environmental systems (Yanuardi et al. 2022). Ultimately, ecological reflexivity aims to overcome the human-nature dichotomy and incorporate the “complexities and systemic interdependencies that define the dynamic world of the Anthropocene” into environmental policy (Biermann, 2021).

In short, ecological reflexivity encompasses the capacity to discern the signals emanating from the natural world. As a result of critical

reflection on an institution’s own actions and inactions, this capacity leads such institution to undergo substantive alterations in its governance principles and arrangements. This transformation becomes especially vital when faced with socio-environmental instability and the emergence of unprecedented, unpredictable phenomena, as exemplified by the arrival of *Sargassum* along the Mexican Caribbean coast (Dobson, 2010; Dryzek and Pickering, 2019, Yanuardi et al., 2022). While the governance of *Sargassum* in Mexico—that is, the way the algae’s management has been regulated, coordinated, and executed—was not originally planned with ecological reflexivity as a guiding principle, we build on what has been done and reflect on opportunities for institutional change as a productive way to stimulate the development of reflexivity (Dryzek, 2016).

THE MEXICAN CARIBBEAN AND SARGASSUM

The Mexican Caribbean coast stretches for nearly 900 kilometers along the Yucatan Peninsula and the state of Quintana Roo (Figure 1). Cancun and the Riviera Maya are renowned tourist destinations with 130 kilometers of beaches, dunes, and mangroves (SECTUR, 2013). Millions of visitors come there every year. In 2022, these destinations received 19.7 M tourists, who generated an economic input of US\$19.4 M for the state (SEDETUR, 2023). Since the 1970s, the development of tourism on the coast of Quintana Roo has resulted in constant urbanization, leading to the creation of new cities such as Cancun, Playa del Carmen, and, more recently, Tulum (Espinosa Coria, 2013). Unplanned urbanization, along with the lack of efficient waste disposal services, good drainage, and wastewater treatment systems, has led to the contamination of the aquifer, the sea, the reefs, and the lagoons, which receive a large part of the urban discharges directly or via infiltration into the subsoil (Metcalfe et al., 2011; Saint Loup, 2018). The construction of hotels, golf courses, and amusement parks on the beachfront has led to the deforestation of mangroves and significantly altered the coastal environment and beach dynamics (Murray, 2007; Brenner et al., 2018; Baker et al., 2020). *Sargassum* inserts

itself into this already complex environment, where institutions have historically shown an unwillingness to establish governance structures

that support the long-term sustainability—as opposed to short-term gains—of tourism in the Mexican Caribbean (Murray, 2007).

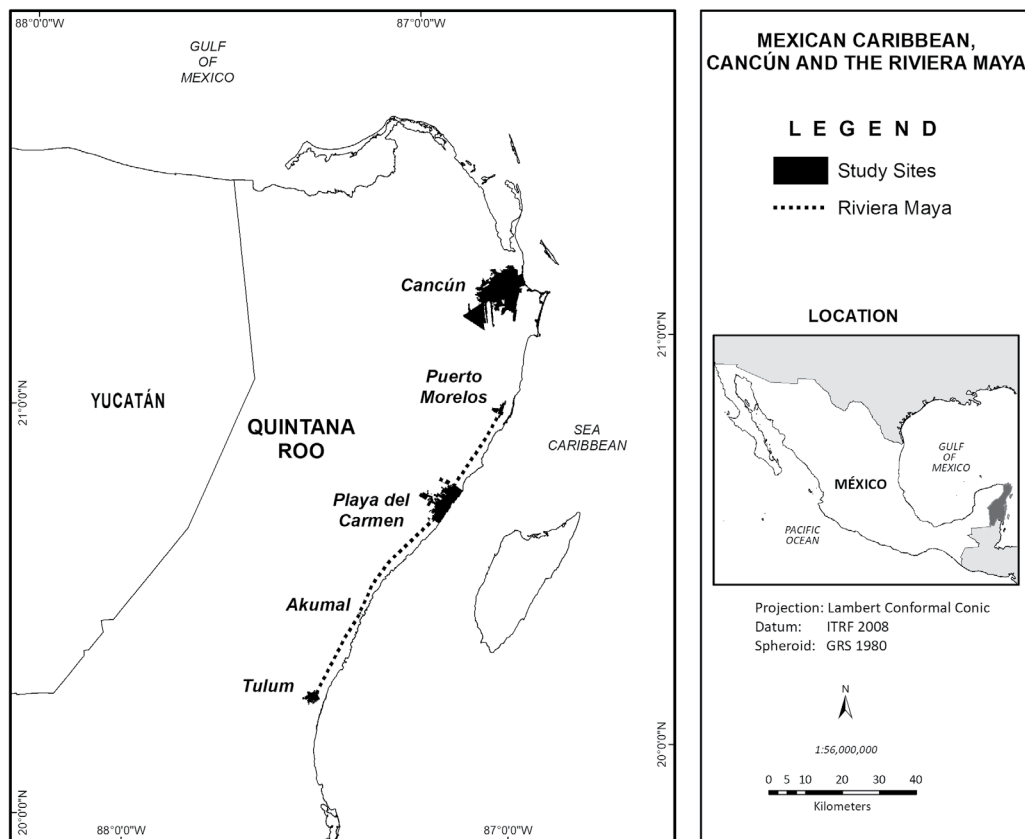


Figure 1. The Riviera Maya coastline and the study sites.

The brown algae that reach the Mexican Caribbean coast belong to two species of the genus *Sargassum*: *S. natans* (Linnaeus) Gaillon, 1828 and *S. fluitans* (B ørgesen) B ørgesen, 1914 (Louime et al., 2017) (*Sargassum* from here on). They grow in the open sea without any structures attaching them to the seafloor, forming extensive, bright golden mats that float freely in the ocean (Wang et al., 2019). *Sargassum* has an accelerated growth rate and can double its volume in about 50 days, although if the input of light and nutrients increases, this period can be reduced to 11 days (Lapointe et al., 2014). In the ocean, the length size of floating *Sargassum* can range from centimeters, for individual algae, to hundreds of meters, if not kilometers, for clumps (Ody et al., 2019).

Caribbean beaches have always received small amounts of *Sargassum* during the year. However,

in 2011, landing volumes began to increase in the eastern region, and by 2014, they had spread to several islands and countries, including Mexico (Gower et al., 2013; Smetacek and Zingone 2013; Franks et al., 2016; Rodríguez-Martínez et al., 2016). In 2015, the Caribbean received a daily flow of ~10,000 tons of *Sargassum*, which, for the northern Mexican Caribbean coast, meant a monthly average influx of 2,360 m³ of *Sargassum* per kilometer of coastline, in the peak landing months (Rodríguez-Martínez et al., 2016; Thompson et al., 2020). The arrival of *Sargassum* decreased considerably in 2016 and 2017, increasing again only in 2018 (Rodríguez-Martínez et al., 2022). After 2018, massive *Sargassum* landings began to occur annually, with mean volumes above 2,000 m³ during the summer months and annual clean-up costs

ranging from 0.3 to 1.5 million dollars per kilometer (Rodríguez-Martínez et al., 2023).

The arrival of massive quantities of *Sargassum* in the Caribbean is an effect of the emerging distribution region in the tropical Atlantic, called the Great Atlantic Sargassum Belt (GASB), which extends from western Africa to the Caribbean and the Gulf of Mexico (Wang et al., 2019). The transport of *Sargassum* from the Sargasso Sea to this new region was influenced by a highly negative phase of the North Atlantic Oscillation in 2009-2010 (Johns et al., 2020). In addition, the increased availability of nutrients in the Atlantic Ocean, mainly from river influxes, upwelling, and Saharan dust, favored the increase in blooms (Wang et al., 2019). From 2011 onwards, seaweed began to flourish and spread in the region, affecting more than 30 countries. In 2018, the GASB extended to about 8,850 km and its biomass was over 20 million tons. It reached 24.2 million tons in June 2022 (Wang et al., 2019; USF, 2022).

METHODS

The analysis presented here is based on research and participation in emergent institutions for addressing the *Sargassum* crisis along the Mexican Caribbean coast. All three authors are university researchers, and one has been directly involved in institutional efforts to manage the crisis. Two authors analyzed relevant policy documents and reports on the *Sargassum* crisis starting in 2015 and conducted qualitative fieldwork on the coast, using methods such as participant observation and interviews. The authors attended seminars and public forums and conducted thirty-four semi-structured interviews in 2018, 2019, and 2022 with various actors directly responsible for the management of emerging conditions or directly affected by *Sargassum* arrivals (e.g. entrepreneurs, tourism service providers, scientists, government employees, hoteliers, fishermen, etc.).

Lastly, a database of media coverage of the *Sargassum* crisis from 2015 to 2022 in two Mexican national newspapers, *El Universal* and *La Jornada*, as well as *Reportur*, an electronic newspaper specializing in tourism, was created. Data from these sources was triangulated to

establish a timeline of events and document the emerging institutional arrangements. The interviews and newspaper reports were entered into a qualitative analysis software (QDA Mine Lite) for coding and analyzed using content analysis techniques to discern how the problem was defined, the stakeholders involved, the agreements reached, the distribution of responsibilities, and the strategies used to address the problem (Head and Atchinson, 2015). Meanwhile, the researcher who participated in the development of institutional efforts drew on the participation in and documentation of institutional responses to corroborate and contribute to the findings and line of argument.

RESULTS

To organize our analysis of the emerging institutional efforts made to manage the effects of *Sargassum* arrivals in Cancun and the Riviera Maya, we build on Rosellón Drucker et al. (2022), differentiating three phases: the first one, from 2015 to 2017; the second one, from 2018 to 2019; and the current one, which began in 2020.

THE FIRST PHASE: IDENTIFYING WHAT IS HAPPENING (2015-2017)

In the Mexican Caribbean, the first massive arrival of *Sargassum* began at the end of 2014. During the initial months, the presence of *Sargassum* was portrayed as “unusual phenomenon” (Aguila Arreola and Vazquez, 2015a). However, by mid-2015, most of the coast of Quintana Roo had received a large influx of algae, which led to enormous concern in the tourist sector (Aguila Arreola and Vazquez, 2015a; Rodríguez-Martínez et al., 2016). The seaweed’s arrival surprised municipal, state, and federal authorities; officials reacted belatedly and confessed to having no strategy to deal with the phenomenon (Restrepo, 2019). Cleaning the beaches became the main focus and was presented as the only necessary measure. The state government and hotel concessionaires with beachfront properties financed the clean-up work (Figure 2). However, only the beaches accessible to tourists were cleaned; on the others, the algae accumulated for months. *Sargassum* was removed by hand

(Figure 2 a-b) or with machines (such as rakes, bobcats, trucks, and bulldozers, Figure 2c) and buried on the beach (Figure 2d) or deposited a few kilometers away. However, the clean-up measures did have consequences. Heavy machinery compacted the sand, which affected turtle nests

and caused beach erosion, as about 40% of the material removed was sand (Rodríguez-Martínez et al., 2016). The clean-up cost was high, and stakeholders and local authorities soon began to request an intervention of the federal government (Reportur, 2015a).



Figure 2. Sargassum cleaned up from beaches manually (a-b) and mechanically (c) and buried in sand (d) in Quintana Roo, Mexico (Photos: R.E.R.M.).

In July 2015, the federal government's Secretariat of Environment and Natural Resources (SEMARNAT) and Quintana Roo's Secretary of Environment (SEMA) established guidelines to reduce the negative impacts of the removal of *Sargassum* from the beach (SEMARNAT, 2015a). By the end of the year, a second set of technical recommendations for the containment and removal

of *Sargassum* from the sea had been published (SEMARNAT, 2015b). SEMARNAT budgeted 60 million pesos (~US\$ 3 million) to hire workers and rent machinery to remove *Sargassum* (Rodríguez-Martínez, et al. 2016). Cleaning the beaches proved to be a valuable but limited strategy, as *Sargassum* landing volumes exceeded the cleaning capacity. In addition, authorities, along

with hoteliers, attempted to prevent the seaweed from reaching the shore by installing barriers.

Members of the SEMARNAT and of the Secretary of Tourism (SECTUR) visited Quintana Roo in July 2015 to observe the impacts of *Sargassum*, declaring that although this was an unprecedented situation, it should by no means be considered an emergency (El Universal, 2015; Águila Arreola and Vázquez, 2015b). The SEMARNAT allocated 15 million pesos (~ US\$ 750,000) to develop a Pilot Project for the Integral Management of *Sargassum* in Puerto Morelos Reef National Park. The project included the installation of 670 meters of barriers, the construction of one harvesting boat, and water quality monitoring. However, the paperwork was slow, and *Sargassum* had stopped arriving by the time the equipment was delivered.

In 2016, *Sargassum* landings were minor and did not cause concern. However, the arrivals resumed in March 2017. To move forward with an integrated *Sargassum* management strategy, individuals in Puerto Morelos, including fishermen, hoteliers, activists, and scientists, organized a stakeholder group to request funds from the Quintana Roo State Secretary of Tourism (SEDETUR) to carry out the 2015 pilot project. But the money was not provided and by 2018, the poorly guarded equipment proved useless for dealing with a new wave of *Sargassum*. Marine scientists from the National Autonomous University of Mexico (UNAM) considered this a missed opportunity to generate experience in containing and removing algae (Varillas, 2018).

In short, the management of *Sargassum* from 2015 to 2018 was characterized by a trial-and-error approach, with few achievements. Government institutions framed the arrival of *Sargassum* as an uncommon event. The emphasis on removing *Sargassum* from beaches, especially those most essential for tourism, with the neglect of other aspects of the problem, such as adequate final disposal to protect aquifers or the protection of coral reefs and other marine species, reveals how the authorities prioritized economic concerns in addressing the *Sargassum* crisis. Treating *Sargassum* as an anomaly that should be removed limited the institutional capacity to respond in

the following years. Nonetheless, the scientific research carried out during this stage led to a better understanding of the ecological impacts of algae influx on beaches, coral reefs, and seagrass beds (Rodríguez-Martínez et al., 2016; van Tussenbroek et al., 2017).

THE SECOND PHASE: GETTING ORGANIZED (2018-2019)

Massive arrivals of *Sargassum* restarted in February 2018 (Rodríguez-Martínez et al., 2022). Landing volumes exceeded those of 2015, which resulted in yet another challenging management situation (El Universal, 2018a; Chávez et al., 2020). In June 2018, SEMA established the *Sargassum* Scientific-Technical Council (SSTC) to gather data on the seaweed, its impacts, periodicity, clean-up methods, and potential uses.

In June 2018, the National Commission of Protected Areas (CONANP) issued an Emergency Technical Opinion to SEMARNAT, indicating that the massive arrival of *Sargassum* could contribute to the deterioration of coral reefs and affect protected marine species. The document called for actions to contain and remove *Sargassum* from coastal waters and the beach. To address the severe impacts on the coast, the federal and state governments provided 322 million pesos (~ US\$17 million) to invest in wages, machinery rental, and the installation of barriers along 27 km of coastline (El Universal, 2018b; El Universal, 2018a; El Universal 2018c; Espinosa and Li, 2020). A private company hired by the SEMA acquired and installed the barriers. These barriers, also called booms, were similar to those designed to contain oil spills, even though the SSTC had already ruled out their usefulness. Their performance was poor and *Sargassum* continued to cover the beaches (El Universal, 2018c; Reportur, 2018a; Rodríguez-Martínez et al., 2019; Chávez et al., 2020). The federal government demanded little supervision and inadequate transparency measures for the resources disseminated to combat the algae. Currently, the federal government is investigating how the funds given to the state of Quintana Roo in 2018 to manage *Sargassum* were used (Restrepo, 2019).

In Puerto Morelos, in July 2018, members of the Hotel Association of Puerto Morelos, academics,

activists, fishermen, and tour operators developed the Puerto Morelos Protocol, a formal strategy for *Sargassum* management. Federal and municipal authorities also participated in the project, along with developers of equipment for containing and cleaning up *Sargassum*. The protocol was an attempt to organize and coordinate actions among the community, government authorities, entrepreneurs, and other actors in order to reduce the impacts of *Sargassum* on coastal ecosystems. The initiative marked the first time that *Sargassum* management was approached with an integrated plan. The protocol included guidelines for the containment, collection, clean-up, and final disposal of *Sargassum* in the municipality of Puerto Morelos. In addition, the protocol suggested that installing barriers close to shore was the most effective strategy to prevent *Sargassum* from reaching the beaches. The algae were to be removed by vessels or redirected to “sacrifice” points at the ends of the barriers and then uploaded to trucks with amphibian bands. The document defined the necessary actions and called for committees to oversee aspects such as detection, containment, extraction, land transport, turtle preservation, etc. The protocol was presented to authorities in February 2019, but it has not been implemented to date (Figure 3).



Figure 3. Presentation of the Puerto Morelos Protocol in February 2019 to municipal, state, and federal authorities (Photo: R.E.R.M.).

In August 2018, the UNAM set up a scientific committee to review the *Sargassum* situation and develop mechanisms for collecting and monitoring algae arrivals (Gaceta UNAM, 2018).

However, the COVID-19 pandemic stopped the committee from meeting, and it has yet to reconvene. In August, the state government created the *Sargassum* Technical Advisory Council (CTAS), with scientists from state institutions, to analyze the *Sargassum* phenomenon (El Universal, 2018d).

In September 2018, the SEMARNAT organized the workshop “Knowledge on the massive landings of *Sargassum* on the Mexican Caribbean Coast: research, management, and collaboration” at the University of the Caribbean in Cancun. Participants were individuals in municipal, state, and federal governments, research institutes, NGOs, and industries working on *Sargassum* clean-up and commercialization. It was concluded that it was necessary to study the chemical composition of *Sargassum*, determine the risks of *Sargassum* decomposition to human health, evaluate the impacts of these algae on coastal ecosystems, and determine the responsibilities of different levels of government, among other factors.

In October, the National Council for Science and Technology (CONACYT) launched a call for proposals with a budget of six million pesos (~US\$ 300,000) to fund research projects and develop a strategy to commercialize macroalgae (Yah Sánchez, 2018). The containment and cleaning of *Sargassum* was already a profitable business, and various companies incorporated seaweed management into their portfolio of services. At the same time, several independent initiatives emerged to find ways to produce and market *Sargassum*-derived products, such as construction materials (e.g., bricks), fertilizers, pharmaceutical products (e.g., alginates and fucoidans), shoes, and paper. All of them are still in the development phase, except for those of three companies manufacturing fertilizers.

In 2018, 522,226 tons of *Sargassum* were removed from tourist beaches in Quintana Roo (Espinosa and Li, 2020). Despite the investment of significant resources, the management strategy was unsuccessful. Hoteliers claimed that there was a drop in visitor numbers, guest complaints, and fewer bookings from high-income tourists (Reportur, 2018b; Reportur, 2018c). Hotel fares were lowered to compensate for cancellations,

and municipal authorities were overwhelmed with the massive algae arrivals. Federal and state government agencies had no coordinated strategy to manage *Sargassum*.

We are learning what works, what does not work, what conditions affect us, whether it is currents, winds, tides, and how the Sargassum behaves, testing containment barriers, extraction cups, different technologies to see what works. (SEMA staff member, 2018)

At the start of 2019, the CTAS presented the “Integral and sustainable *Sargassum* management plan for the Mexican Caribbean”, or PLANSARG, a management strategy to reduce environmental and socio-economic impacts (CTAS, 2019). According to this plan, the most efficient solutions consisted of “containing the floating masses of *Sargassum* at a sufficient distance from shore, so that they do not affect coastal ecosystems,” and preventing decomposition on the beach and erosion (CTAS, 2019:11). The plan suggested using mobile barriers and boats to concentrate and extract *Sargassum* in certain areas, describing actions for the early monitoring of the seaweed, its final disposal, and possible uses. However, council members acknowledged that “the solution to the problem would not end with the above, because if we want to solve it at its root, we must promote more forceful public policies to dramatically reduce the sources of ocean pollution and the anthropogenic causes of climate change” (CTAS, 2019:11) PLANSARG has not yet been implemented.

In 2019, the first arrivals of *Sargassum* were recorded in April, and the abundance of *Sargassum* soon became alarming. As Cancun’s mayor recognized, “the problem is severe, due to the speed with which the *Sargassum* volumes arrive” (Varillas, 2019b). At the same time, the state governor claimed that “the massive arrival of *Sargassum* is a matter of federal responsibility” and requested 405 million pesos (~US\$ 20 million) to implement a comprehensive strategy (Varillas, 2019b). The National Fund for Tourism (FONATUR) estimated that the cost for removing *Sargassum* in

Quintana Roo during 2019 would be around 1,000 million pesos (~ US\$ 50 million) (Vázquez, 2019).

In April 2019, a project called “Escudo del Caribe” was presented as an alternative for the integral management of *Sargassum*. Developed by a group of institutions, along with biologists, engineers, and businesspeople, the plan included satellite detection, coastal video surveillance, maritime detection with boats, hydrodynamic and meteorological studies to model the dynamics of *Sargassum* movement, the development of a *Sargassum* forecast, mechanisms for the proper disposal of the algae in defined sites, and the recovery of sand mixed with the organic matter collected. But the alleged links between the company in charge of the project and FONATUR officials and businesspeople in the region were deemed inappropriate, and the initiative was eventually dropped (Noticaribe, 2019). Similar plans to deal with the macroalgae were proposed by research centers and NGOs, but none were carried out (Varillas, 2019c). At that time, many individuals and companies sought to access public funds for *Sargassum* containment by obtaining or extending contracts for seaweed collection, transport, and disposal.

By May 2019, Quintana Roo had still not received economic resources from the federal government and was dealing with the situation with its own funds; and hoteliers continued to finance the cleaning of their beachfront properties (El Universal, 2019a). In May, the state government presented the “Emergency Protocol for the Attention of Sargasso,” inspired by the Puerto Morelos protocol, and weeks later declared that Quintana Roo was facing an imminent natural disaster (Varillas, 2019d; Reportur, 2019a). Quintana Roo officials insisted that, as the sea is a domain of the federal government, they should be the ones to bear the costs of containing and removing the *Sargassum*. At the same time, the Senate of the Republic proposed that the Secretariat of the Interior (SEGOB) declare a federal emergency so that state authorities could benefit from economic resources through the National Disasters Fund (FONDEN) (El Universal, 2019b).

In June, UNAM researchers sent a letter to the SEMARNAT about the need for an official Mexican policy (NOM) to regulate the management and use of the massive *Sargassum* landings. They proposed that the algae be treated as “special management residues” due to the fact that they produced poisonous gases during rotting and that their tissues had toxic elements such as heavy metals. The SEMARNAT claimed that the matter was outside its purview because it involved human health concerns; consequently, Quintana Roo authorities oversaw residue management.

In the same month, President López Obrador announced his strategy for dealing with the *Sargassum* crisis at a press conference. To the bewilderment of many, this strategy did not include releasing public resources to the state government. Instead, López Obrador established a centralized strategy for *Sargassum* and made the Navy (SEMAR) responsible for its design and implementation. The president stated that he would not issue a disaster declaration because doing so would allow private companies to be hired without bidding, which would facilitate corruption and resource deviation. Moreover, he claimed that the presence of *Sargassum* was not a serious problem: “We are going to deal with the *Sargassum* issue; I have not spoken much about it because I do not consider it to be, as some argue, extremely serious” (El Universal, 2019c). State authorities, hoteliers, scientists, and tour operators were shocked and questioned the president’s stance (Reportur, 2019b; Urrutia, 2019a).

SEMAR’s approach consisted of building eleven *Sargassum* removal vessels and installing 9.9 km of barriers to prevent *Sargassum* from reaching the public beaches of the main tourist destinations. Municipal workers were to manually remove the beached algae, while aircraft were to be used to monitor the presence of *Sargassum* (Urrutia, 2019a). For the latter, 109 and 84 million pesos (~US\$ 5.5 and 4.2 million) were allocated, respectively (SEMAR, 2022). These resources represented a small proportion of the amount invested in previous years, which exceeded \$800 million (~US\$ 40 million) in President Enrique Peña Nieto’s six-year term (Restrepo, 2019; Urrutia, 2019b).

The state government contributed 180 million pesos (~US\$ 9 million) to the federal containment plan (Vázquez, 2019). Part of the money came from the collection of fees for the use of the Federal Maritime Terrestrial Zone (Varillas, 2019b) and of a new environmental sanitation fee charged to tourists (Alegría, 2019). The state government was responsible for establishing municipal sites for the final disposal of *Sargassum*, but these were never created. While the SEMAR built its boats, the *Sargassum* was collected using existing infrastructure (Espino, 2019). Large hotels acquired barriers, vessels, and machinery to remove the *Sargassum* (Reportur, 2019c). Hotels with fewer resources hired clean-up companies or relied on the actions of the state government and municipalities.

On June 27, 2019, the state of Quintana Roo and the private sector held an international meeting in Cancun to advance regional cooperation among Caribbean countries (Encuentro de Alto Nivel para la Atención del Sargazo en el Gran Caribe). The meeting aimed to promote better understanding of the *Sargassum* phenomenon, identify the actions needed in the medium and long term, and seek funding mechanisms. Due to misunderstandings between authorities, federal government officials did not attend. More than 600 people took part, including tourism and environment ministers from thirteen countries. Twenty-six agreements were reached, such as the establishment of an international cooperation agenda to analyze the phenomena and allocate funds to solve immediate problems (Reportur, 2019d).

A second meeting was held on the island of Guadalupe in October. There, the Head of Mexico’s Office of the Secretariat of Foreign Affairs (SRE) stated that (Varillas, 2019a):

The bad news is that Sargassum is here to stay; it is not temporary. Whoever believes that Sargassum will disappear does not understand what they are saying; worse still, if the dumping of all industry continues in all the world’s oceans, Sargassum will increase rather than decrease... On the other hand, we dump nutrients so that the

Sargassum is produced at a faster rate... there is not enough money... [to cope with the arrival of the algae].

At the end of 2019, SEMAR reported the collection of more than 84,000 tons of algae between May and October on the high seas and 18 km of beaches (Espino, 2019). In the same year, hotels in the northern sector of the state reported the monthly removal of nearly 500 tons of seaweed per kilometer (Rodríguez-Martínez et al., 2022).

In September 2019, the Senate's Commission on Science and Technology, in collaboration with the SRE, held an event in Mexico City called "Sargassum: Challenges and Opportunities". Over 80 academics, government authorities, and national and international organizations attended the event. The final conclusions included the acknowledgement of the fact that the dimension and scope of the phenomenon required special attention from different governmental and non-governmental organizations and the recognition of the need for international cooperation and agreements to establish standards.

In 2018 and 2019, *Sargassum* landings peaked. The highest volume arrivals occurred during seven and five months, respectively (Rodríguez-Martínez et al., 2022). Raising the funds needed to pay for *Sargassum* clean-up and collection was the main concern of state authorities. Once again, federal and state institutions prioritized the tourist economy and allocated millions of pesos to contain and remove *Sargassum* from the beach. This is partly understandable, given the substantially higher costs associated with the collection of the seaweed from the sea (Rodríguez-Martínez et al., 2023). Not surprisingly, the containment and removal of *Sargassum* became profitable activities. However, clean-up actions were insufficient to prevent ecological and economic impacts. Few beaches were cleaned and *Sargassum* decomposition caused massive mortality of marine life on several beaches (Rodríguez-Martínez et al., 2019). The quality of coastal waters deteriorated, and a new coral disease emerged in May 2018, causing a further decimation of reef populations (Alvarez Filip et al., 2022).

In short, despite advisory boards, commissions, and numerous state, federal, and international meetings to find solutions and organize actions, *Sargassum* management lacked coordination and was sporadic. State, federal, and municipal authorities disagreed on their respective responsibilities. Initiatives started in earlier years were duplicated, often with the same outcomes. Management protocols were abandoned after a huge investment of time and expertise. Moreover, President Lopez Obrador's claim that *Sargassum* did not represent a major problem was an enormous disappointment for the local actors who witnessed the piles of decomposing *Sargassum* and for the scientists who observed the death of seagrass beds and coral reef fauna and the suffocation of marine turtles. All the meetings organized over those years indicated that there was a search for more complex policy responses that integrated and coordinated other actors at various scales and incorporated ecological concerns in addition to economic ones. Likewise, relevant actors developed a more complex understanding of the algae and their arrival over the years. *Sargassum* came to be seen as "here to stay," and its presence was linked more concretely to the release of nutrients into the sea and, more generally, to global warming.

THE CURRENT PHASE: CENTRALIZING RESPONSES (2020-2022)

In 2020, the COVID-19 pandemic led to a significant reduction in tourism. In addition, *Sargassum* arrivals started later than in 2018 and 2019 (Reportur 2020a; Reportur, 2020b). The federal budget for the year did not include a specific line item for *Sargassum*, but the resources allocated to the SEMAR were above 85 million pesos (~ US\$ 4.2 million) (El Universal, 2020a; Reportur, 2020a). The SEMAR continued to lead seaweed containment efforts in the same way as the previous year (El Universal, 2020b). Scientists, NGOs, and other stakeholders expected the official guidelines for the management and industrialization of the macroalgae to be released that year. However, the lack of accurate information on the

abundance, seasonality, uses, and ownership of the algae has so far prevented the publication of these guidelines (Reportur, 2019e; Senado de la Republica, 2021).

In 2021, the arrival of *Sargassum* was moderate. The SEMAR continued to collect *Sargassum* from the sea and carry out aerial surveillance near the affected municipalities. The nearly ten kilometers of containment barriers installed in 2019 were still in use. Municipalities continued to clean public beaches and employed more than 600 people via temporary employment programs, in addition to using *Sargassum* collecting bands, bobcats, and heavy machinery (Castillo, 2021). The federal government made progress in the implementation of monitoring instruments and institutional strengthening, developing the *Sargassum* Monitoring System (SIMSAR) to systematize the volume of *Sargassum* collected; municipal manuals for the management and collection of the algae; and mechanisms for the systematization and harmonization of actions carried out to deal with this phenomenon (El Universal, 2021). In addition, a federal satellite-based *Sargassum* early warning system (SATsum) was developed, providing daily alerts on the presence of floating *Sargassum*. Nonetheless, it is still unclear how *Sargassum* monitoring and warning systems are used in decision-making.

Some hotel associations, academic groups, and environmental organizations were not satisfied with the emerging strategy and used a Change.org petition called “S.O.S. We are sinking in *Sargassum*!” to ask the federal government for better coordination, a larger budget for the containment and collection of seaweed on all beaches; and the implementation of an official Mexican policy for the integral management of *Sargassum* (Vazquez, 2021).

It is the same thing year after year, six years after six years. Now the six-year term of this [state] government is coming to an end and what has been done? They have changed the Secretary of Ecology twice, and what progress has been made? NGO Member, 2022.

In 2022, the coasts of Quintana Roo once again received enormous volumes of *Sargassum*. Few changes were made to SEMAR’s strategy, while some municipalities, such as Benito Juárez, increased their beach cleaning efforts by organizing voluntary work days called “Everyone against *Sargassum*” (Varillas, 2022). In addition to the effects on tourism, the press began to report other consequences of *Sargassum* landings, including health problems for people exposed to *Sargassum*’s decomposing gases, beach erosion, the contamination of aquifers by *Sargassum* leachates, and an increase in the contamination of cenotes (natural freshwater ponds fed by underground rivers unique to the Yucatan Peninsula), as well as a boost in tourist visits to these locations, increasingly promoted as alternatives to the beach (Casas Beltran et al., 2020; Olguin Maciel et al., 2022).

DISCUSSION

As outlined here, managing *Sargassum* proliferation is a significant challenge for existing institutional arrangements. Nonetheless, the governance of *Sargassum* in Quintana Roo introduces some positive opportunities that may stimulate ecological reflexivity. One of these is the participation of a wide range of actors in the committees and councils for managing the massive arrival of the seaweed. This is particularly relevant in the case of the Puerto Morelos Protocol, a consultative body in which residents, businesspeople, authorities, fishermen, and scientists, among others, discussed and cooperated in developing and implementing strategies to manage *Sargassum*. Similarly, the interviewees and the sequence of events reconstructed from newspaper reports show us how actors such as hoteliers, NGO members, and small businesses are willing to think about, design and test different solutions and adjust their strategies according to the effectiveness of results. We see these processes, for example, in the way the design and placement of anti-*Sargassum* barriers has evolved, as well as in the changes in methods of collecting *Sargassum* from the beach and disposing of it, which have been aimed at reducing the removal of large

quantities of sand and the seepage of polluting leachate into the subsoil. Baker et al. (2020) have already documented the implementation of hybrid governance to prevent water pollution in the Riviera Maya, in which private actors collaborate with the government to enhance regulations and exchange their knowledge and data with the public sector. These prior experiences are likely to facilitate stakeholder involvement and cooperation in the management of *Sargassum*.

Scientific research over the last decade has been crucial, improving our understanding of the impacts of *Sargassum*. These studies show the multiple effects of *Sargassum* on human and nonhuman communities, including coral reefs, seagrasses, turtles, fish, and other marine species facing unprecedented threats to their well-being (Maurer et al., 2021). Furthermore, there is growing evidence indicating that prolonged exposure to decomposing *Sargassum* poses risks to human health (Resiere et al., 2018; Devault et al., 2021). The skills acquired over the years and the greater knowledge on *Sargassum* and what it can do have also led to a rethinking of the values and beliefs underlying *Sargassum* governance. If, in the beginning, the presence of *Sargassum* was seen as an isolated event and the seaweed was considered waste or garbage to be removed from the beach, today, *Sargassum* landings are understood as a new feature of the environment. There is already talk of a “*Sargassum* season,” especially during the summer months. *Sargassum* is now treated as a potential resource whose use could be part of the solution to the problem.

However, we also identified some obstacles to the articulation of a reflexive governance scheme suited to the changing dynamics of the Mexican Caribbean. On the one hand, we found an unresolved tension between the centralized management system and a more dispersed model (Dryzek and Pickering, 2019). The three levels of government in Mexico are involved in *Sargassum* management, but their responsibilities are not clearly defined, which leads to fragmented institutional responses. At the federal level, algae control is centralized in the SEMAR, which is primarily concerned with the containment and collection of *Sargassum* at sea. Other activities, such as

cleaning *Sargassum* from the beach, transporting it for final disposal, managing landfills, monitoring, or generating knowledge, are the responsibility of Quintana Roo authorities, municipalities, universities, research centers, and entrepreneurs. The lack of coordination and oversight has led to the duplication and overlapping of responsibilities. The SEMARNAT guidelines (SEMARNAT, 2015a, 2015b, 2019) are important for developing a legal framework to guide actions towards the desired scenarios. However, they are still in their initial stages, as evidenced by the requests from different actors to clarify and strengthen the legal instruments related to *Sargassum* management. The presence of numerous authorities, overlapping functions, and disconnected actors is not unique to *Sargassum* management: it may be a predominant aspect of environmental governance in Mexico, as noted in other areas impacted by tourism, such as the Bahías de Huatulco in the Oaxaca state and the southern coast of Jalisco (Martínez Rodríguez et al., 2019; Gutierrez Estrada, 2022).

On the other hand, we observed that the institutional principles and strategies driving governance place an emphasis on maintaining the ability of the tourism industry to generate short-term profits, even as coastal degradation threatens its long-term prospects (Baker et al., 2020; McAdam-Otto, 2023). As a result, funding is being directed towards monitoring seaweed and keeping it away from the coast, as well as cleaning beaches for tourists. By putting tourism at the center of attention and beach cleaning as the primary activity, other consequences, perhaps less immediate and obvious, but not less serious, are sidelined and lead to new problems that aggravate the situation (i.e. the contamination of aquifers; health problems).

Lastly, the reluctance to consider how tourism and existing institutions contribute to the phenomenon is another obstacle we identified. Federal and state institutions frame *Sargassum* as an external threat instead of recognizing it as an indicator of changing ocean dynamics linked to existing socio-ecological arrangements. Mangrove deforestation, coral white syndrome, groundwater pollution, nutrient enrichment of coastal environments, and degradation of turtle nesting

habitats are some of the ecological degradation processes in the Riviera Maya that affect marine and coastal ecosystems, some of which contribute to algae proliferation (Brenner et al., 2018; Casas-Beltran et al., 2020; Pérez-Gómez et al., 2020; Ulloa et al. 2017).

However, not all is lost. A recent turn of events is creating new opportunities to transform *Sargassum* management on the Mexican Caribbean coast. After suspending its meetings for several months in 2022, the CTAS was reactivated in January 2023 and worked on a national strategy for *Sargassum* management, which was presented in October 2023 (Rodríguez-Martínez et al., 2023b). At this pivotal moment, we suggest that Dryzek and Pickering's (2019) insights on ecological reflexivity offer promising guidelines for environmental governance. Specifically, our findings suggest the need for a serious reflection on and reconsideration of tourism in Cancún and the Riviera Maya. To meet the demands of emerging socio-ecological transformations, tourist development policies need to consider social and economic dynamics, but also address the environmental impact of Quintana Roo's tourism sector (Bramwell and Lane, 2011).

CONCLUSION

This article outlined the challenges for coastal management posed by poorly understood and unpredictable phenomena such as the massive arrival of *Sargassum* in the Riviera Maya. We examined the environmental and economic harm caused by the algae, as well as the measures taken by the Mexican government and other stakeholders to address the situation. We also identified the challenges encountered and the progress made. With a detailed examination of the response to the *Sargassum* crisis in Mexico, this article shows that recognizing and continuously reviewing institutional inadequacies and shortcomings, as well as the environmental consequences of implemented strategies, is crucial for dealing with *Sargassum* blooms. It also highlights the concept of ecological reflexivity as a means of adjusting governance to the new conditions of the Anthropocene.

Today, after almost ten years, *Sargassum* arrivals have evolved from a random occurrence to a

seasonal phenomenon. However, the high levels of algae often cause conditions to spiral out of control. For this reason, the principle of ecological reflexivity is key to evaluating and rethinking the actions taken and to search for a more effective way to manage *Sargassum* arrivals, not only in Mexico, but also throughout the entire Caribbean region. Reflection on institutional mistakes and failures should be seen as a necessary part of generating effective responses to surprising and unknown phenomena such as *Sargassum* blooms. However, what constitutes an action or response needs to be extended beyond the design and implementation of useful technology and equipment to contain, manage, and dispose of the algae. To deal with the new conditions of the Caribbean coasts, institutions will need clear objectives and responsibilities; the capacity to cooperate and act in a coordinated manner; detailed and accessible monitoring and information systems; strategies for monitoring and evaluating policies; adequate funding for the implementation of management strategies; and broad and deliberative participation mechanisms.

Similarly, the dynamics of other organisms with shared characteristics, such as weeds and invasive species, suggest that eradication or total control is not a feasible goal; therefore, it seems more appropriate to prepare for coexistence with *Sargassum* (Head and Atchinson, 2015; Head et al., 2015). It is important to remember Dryzek and Pickering's (2019) suggestion that ecological reflexivity involves listening to signals from the natural world and fostering the capacity to change institutional arrangements in response (Dobson 2010). From this perspective, listening to *Sargassum* compels responses that are not solely concerned with human interests such as the maintenance and expansion of large-scale tourism, which currently defines the socio-cultural dynamics of the region and the strategy currently implemented to deal with *Sargassum* (Sheik et al. 2023; Offor and Cardeza Salzmann, 2022; Durand and Sundberg, 2022).

Ecological reflexivity is an emerging concept, not yet fully resolved in practice to suggest specific transformations and concrete actions in governance systems for dealing with situations such as *Sargassum* blooms. However, the few existing case studies already suggest some

relevant lines of work (Fukanaga, 2022; Connoly, 2020). In the specific case of the Mexican Caribbean, it would be important to explore the possibility of focusing governance not on the consequences of the arrival of *Sargassum*, but on the human-non-human networks that make it possible to have idyllic beaches of white sand and turquoise sea that attract tourists. It is crucial to examine the integration of non-human entities into governance systems and the planning of regional tourism. This analysis should include a thorough evaluation of the physical and behavioral shifts of organisms such as algae and corals and the local and scientific comprehension of the environment. Additionally, there is a need to recover the history of the alteration of coastal environments and the consequences that these changes have had on people's livelihoods and identities. As Fukanaga (2022) suggests, the challenge for the governance of new environments in the Anthropocene is to stop living off non-human nature and start living with and for it. Our aim with this paper is to advance these areas of study, which, although still theoretical, offer new perspectives and imply that managing the *Sargassum* crisis requires more than just algae control: it involves envisioning and restoring relationships that promote a healthy Atlantic Ocean and a healthy planet.

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AUTHOR CONTRIBUTIONS

L.D.: Conceptualization; Investigation; Writing – original draft; Writing – review and editing.

J.S.; R.E.R.M.: Investigation; Writing – review and editing.

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