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Analysis of the Real-Time Phases of Adaptation Through the Lens of an Emergent Risk: Sargassum Adaptation Policy Analysis in the Caribbean

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Abstract: Since 2011, countries across the tropical Atlantic have experienced severe influxes of the seaweed species *Sargassum natans* and *Sargassum fluitans* (henceforth, "sargassum"), with nearshore and onshore ecological, economic and social impacts locally and regionally. Not all affected countries have had the same response to this emergent environmental challenge. Here, we explore the first ten years of policies produced in response to sargassum influx risk across islands in the Wider Caribbean Region, considering the variation in form, content and aim of sargassum adaptation policies. This assessment of the variation in Caribbean adaptation policies allows lessons to be identified for rapid adaptation to emergent environmental challenges. We find that several countries have no national policy for sargassum adaptation, and many subnational island jurisdictions have no island-specific policies. Whilst there is increasing anecdotal evidence of private and local adaptations taking place to address sargassum influx events, there remains significant scope for government leadership and resource support in adapting to this emergent threat. The lesson is that private adaptations to emergent threats may be quicker to develop and execute than policy adaptation, but longer-term, larger-scale adaptations depend on evidence-based, widely supported government policies with clear avenues of funding.

Keywords: emergent risks; adaptation; SIDS; climate change; Caribbean; sargassum

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1. Introduction

Small islands are among the world's most vulnerable sites to climate change, and as they adapt to emergent threats, they can act as forerunners to environmental change management elsewhere [1,2]. Since 2011, small islands in the Caribbean have been experiencing anomalous massive influxes of the macroalgae species *Sargassum natans* and *Sargassum fluitans* (henceforth, "sargassum"). These influxes are unpredictable in timing and severity and little understood, but they bring a potential new and abundant resource—seaweed biomass and biodiversity—into Caribbean coastal areas [3]. The more immediate widespread experience has been negative, with issues arising for local ecosystems, health, tourism, fisheries and livelihoods [4]. While there is a growing body of research on the origins, commercialisation and forecasting of sargassum influxes [5], there has been less focus on responses to sargassum influx events [6]. We fill this gap by comparing the varying forms and contents of sargassum adaptation policy and practice across both sovereign and non-sovereign Caribbean small islands. We ask the following question: what is the evidence in the policy

for adaptations to sargassum developed since 2011, and what lessons do these adaptations provide for responding to emergent environmental challenges?

The drivers of sargassum influxes remain uncertain but appear to be linked to the interaction among oceanic circulation patterns, climate variability and climate change [7,8]. Sargassum events, as experienced in the tropical Atlantic since 2011, are unprecedented situations and represent an emergent threat for which new adaptation strategies are required. Prior to 2011, the main narrative associated with sargassum was focused on natural dynamics and human uses in the Sargasso Sea, but with the seaweed now present at much greater abundance across the tropical Atlantic, sargassum is presenting new challenges to the conservation sector, as well as other sectors, including fisheries and tourism [3]. Sargassum influxes represent an emergent threat with a similar character to the risks to small islands from climate change-related processes, as described by Working Group II in the *Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; they are a transboundary emergent threat to small islands with high vulnerability, the driving processes of which originate well beyond their borders [9]. Emergent risks arise from the interaction of phenomena in a complex system and are increasingly apparent in small islands [10]. However, at the time of AR5 and its chapter focused on emergent risks [10], macrophyte seaweeds were not identified or recognised as potential examples of emergent risks to coastal communities. Furthermore, most small island developing states (SIDS) research on climate change adaptation is focused on the Pacific and sovereign SIDS [11], and there remains a dearth of comparative analyses as well as a lack of focus on adaptation barriers and limits in the context of small island adaptation research [12].

While the science of emergent, transboundary risks remains relatively new, assessments of adaptation across scales are now commonplace, with associated frameworks to review the adaptation process. Biagini et al. [13] and Klein et al. [14] present typologies of adaptation actions and parameters, respectively, both of which have received widespread application in the ensuing years. The typologies emphasise the prevalence [13] and significance of governance and institutional factors in effective adaptation [14], for example, that institutions need mandate and capacity to be able to select and implement adaptation options. However, existing adaptation frameworks do little to explore capacities and opportunities for adaptation to emerging threats, such as sargassum. Many of the factors relevant for adapting to climate change-driven changes are likely to be equally relevant for adaptation to emerging risks [10,15]. Nevertheless, exposure to a hazard or environmental phenomenon not previously experienced in a locality, nation or region may also require a unique set of capacities and necessitate rapid adaptations in response to its occurrence. The response of Caribbean states and territories and regional mechanisms and organisations provides an opportunity to identify what does and does not work effectively in the policy and process of developing rapid adaptation responses to emerging threats.

This paper uses sargassum to assess the variation in adaptation policies across islands in the Wider Caribbean Region (WCR) to identify lessons for rapid adaptation to other emergent environmental challenges. We achieve this through an analysis of adaptations that have taken place in policy and practice from 2011 to 2021, comparing the variation between territories and identifying the lessons learned for developing rapid responses to emergent threats. First, we outline why sargassum is an important case to examine these questions and the methods and data we have compiled to do so. The bulk of the article comprises a comparative analysis of sargassum management plans. We compare both substantive and process differences (i.e., what the policies state and how they are compiled). The conclusion returns to the key themes and outlines the lessons learned to support adaptation to other emergent threats, as it is a significant factor in adaptation to emergent environmental threats among small island developing states (SIDS).

2. Materials and Methods

In this paper, we identify lessons for rapid adaptation to emergent environmental challenges from a case study of national and regional adaptation to sargassum influxes in the Caribbean. This region is often regarded as a "laboratory" for comparing political institutions due to the amount of variation apparent in otherwise relatively similar economic and historical contexts [16,17]. Small islands, with their proportionally large coastlines, are particularly exposed to ongoing and future climate change impacts due to rising global mean sea levels, other climate-related ocean changes and further adverse effects from human activities on ocean and land [15]. Caribbean SIDS already face coral bleaching, drought and flooding; the population occupying the coastal zone is continuing to increase; and the costs of climate change impacts across sectors may be as high as 1.5–5% of the region's GDP [15,18]. Yet, in the Caribbean, there are physical data gaps that limit climate change risk forecasting [9], as well as adaptation data gaps; a systematic literature review concluded that most SIDS research is focused on sovereign small islands in the Pacific [11].

Sargassum was sighted in the Caribbean prior to 2011 but in nowhere as great a volume as it now engulfs coastal ecosystems and beaches throughout much of the year [6]. A number of countries have developed management guidelines, briefs and policies for this environmental threat [19]. We assess the variation in sargassum adaptation across the WCR using thematic analyses of these policy documents to identify lessons for rapid adaptation to emergent environmental challenges. We undertook a systematic search of policy documents related to environmental (and specifically sargassum) management in the WCR. In the sampling process, WCR continental territories were excluded from the policy collection, as these states typically do not face as many complexities pertaining to their sovereignty and self-governance or the challenges associated with the physical geography of "islandness" (i.e., high coast-to-land ratio, multiple island jurisdictions and high exposure to rising sea levels). The focus of the policy search and this analysis was limited to Caribbean states and Small Non-sovereign Island Jurisdictions (SNIJs), with their distinct characteristics of high coast-to-land ratio relative to continental states and multiple environmental threats to sovereignty [20,21].

A brief overview of the thirty-two Caribbean states and territories that were included in the search for policy documents is provided in Table 1. The majority of territories included in this analysis have population sizes well below 1 million and territorial land sizes ranging from thirteen square kilometres (Saba) to a maximum of 109,820 square kilometres (Cuba). Small islands have a relatively larger coastal area to manage [9], which is especially pertinent with regard to coastal threats such as sargassum. Only five of the thirty-two territories are not classed as SIDS (and those five are SNIJs with minimal self-jurisdiction), and eight of the fourteen sovereign states are developing economies [22]. Developing economies and SIDS face significant constraints in adaptation [14], as well as barriers including limited access to resources (financial, technological and human), an emphasis on development over sustainability, focus on short-term climate variability over long-term climate change, a preference for hard adaptation measures over soft (natural) measures and issues related to cultural and social acceptability of measures [23] Access to international adaptation finance is one of the primary barriers and limits to adaptation action in SIDS [24]. These barriers and constraints may similarly limit SIDS' capacity to adapt to sargassum influxes.

In addition to the hypothesised size-driven limitations to sargassum, the territories in Table 1 were selected for analysis because they allowed for a comparison between sovereign island states (fourteen) and SNIJs (eighteen). Non-sovereignty is correlated with higher levels of GDP per capita but also reduced adaptive capacity due to limited negotiating power and a lack of consideration by the decision-making bodies [25], as well as a reliance on finance from

the metropole [26]. A report on climate change governance at the subnational government scale revealed numerous factors constraining subnational adaptation, including the diversity of subnational governments limiting vertical integration, a lack of full jurisdiction, policy gaps between national and subnational policies, weak technical and coping capacities, a lack of leadership and a lack of funding and financial resources [27].

Table 1. Overview of sovereign states and Subnational Island Jurisdictions considered in this research.

State	Sovereign Status	Land Territory in sq km	Population Size	Single/Multiple Islands	GDP per Capita (USD in 2020)
SNIJs					
Anguilla	BOT, UK	91	18,090	Multiple	20,438
Bermuda	BOT, UK	54	71,750	Multiple	108,161
British Virgin Islands	BOT, UK	151	37,380	Multiple	36,107
Cayman Islands	BOT, UK	264	61,940	Multiple	85,134
Montserrat	BOT, UK	102	5370	Single	12,017
Turks and Caicos	BOT, UK	948	55,900	Multiple	26,866
Aruba	CC, NL	180	119,430 *	Single	21,302
Bonaire	PB, NL	288	20,900 *	Single	Not reported
Curaçao	CC, NL	444	151,350 *	Single	18,658
Saba	PB, NL	13	1900 *	Single	Not reported
Sint Eustatius	PB, NL	21	3100 *	Single	Not reported
Sint Maarten	CC, NL	34	44,564 +	Divided island	26,683 (2015)
Guadeloupe	OD, France	1628	373,500	Multiple	Not reported
Martinique	OD, France	1128	356,000	Single	Not reported
Saint Barthélemy	OT, France	25	7116 +	Single	Not reported
St Martin	OT, France	54	32,680 +	Divided island	Not reported
Puerto Rico	UT, USA	8959	3.1 million +	Multiple	Not reported
US Virgin Islands	UT, USA	346	105,870 +	Multiple	Not reported
Sovereign states					
Antigua and Barbuda	Sovereign	442.6	98,180	Multiple	14,016
Bahamas	Sovereign	10,010	337,700	Multiple	29,216
Barbados	Sovereign	430	294,560	Single	15,191
Belize	Sovereign	22,806	399,600	Multiple	3999
Cuba	Sovereign	109,820	11.1 million	Multiple	8940
Dominica	Sovereign	751	74,200 *	Single	6824
Dominican Republic	Sovereign	48,320	10.5 million	Multiple and Divided Island	7253
Grenada	Sovereign	344	113,090	Multiple	9360
Haiti	Sovereign	27,560	11.1 million	Multiple	792
Jamaica	Sovereign	10,831	2.8 million	Multiple	4692
Saint Kitts and Nevis	Sovereign	261	53,800 *	Multiple	16,502

Table 1. *Cont.*

State	Sovereign Status	Land Territory in sq km	Population Size	Single/Multiple Islands	GDP per Capita (USD in 2020)
Saint Lucia	Sovereign	606	166,490	Single	8335
Saint Vincent and the Grenadines	Sovereign	389	101,390	Multiple	6998
Trinidad and Tobago	Sovereign	5128	1.2 million	Multiple	15,557

* British Overseas Territory United Kingdom (BOT UK), Constituent Country, Netherlands (CC NL), Public body, similar to municipalities, The Netherlands (PB NL), Unincorporated Territory, United States of America (UT USA), Overseas Département (OD), Overseas Collectivity (OT), sovereign UN member state (Sovereign) and population size as of July 2020, + for July 2021, or * where date not known. Population, land territory, and number of islands data obtained from the CIA Factbook [28], except for Bonaire, Saba and Sint Eustatius [29,30] and Guadeloupe, Martinique and Guyana [31]. GDP per capita from [32].

Sixteen policy documents, plans and guidelines were identified that had been produced in the decade (2011–2021) since the first significant series of sargassum influx events in 2011 (see Tables 2 and S1). These documents were identified by searching government websites and, when not directly available, contacting relevant bodies and individuals to request further information and/or access. Two of these are the policies for (i) the entire Dutch Caribbean and (ii) the entire French Caribbean. The other fourteen documents are either territory-specific or sovereign-specific. Sargassum adaptation is a fast-moving space, and both draft and finalised policies are not always publicly available. This study is limited by its inclusion of only those policies that were publicly accessible or shared directly with the researchers. Whilst only sixteen sargassum-specific policy documents were identified, it is possible that sargassum is managed within other policy arenas, and those taken into consideration in this study are disaster/hazard management, climate change adaptation, biodiversity, invasive species, fisheries, environment and national development. These policies were examined to determine whether there was any inclusion of sargassum within the document.

Table 2. Overview of sargassum adaptation policies in the Caribbean.

Territory	Policy (Year)	Type	Aim	Focus
		SNIJs		
Anguilla (UK)	Yes *	Draft management plan	Unknown	Unknown
Bermuda (UK)	No	N/A	N/A	N/A
British Virgin Islands (UK)	No	N/A	N/A	N/A
Cayman Islands (UK)	Yes (2015)	Removal guidelines	None explicitly stated.	Background information. Removal/clean-up best practice.
Montserrat (UK)	No	N/A	N/A	N/A
Turks and Caicos (UK)	Yes *	Draft management plan	Unknown	Unknown
Dutch Caribbean †	Yes (2019)	Management brief	None explicitly stated.	Removal/clean-up best practice. Solutions for collection and use.

Table 2. *Cont.*

Territory	Policy (Year)	Type	Aim	Focus
Bonaire (NL)	Yes (2021)	Management plan	To cover all aspects of detecting, preventing and addressing sargassum.	Operational structure that applies during an influx event. Stakeholder roles and responsibilities.
French Caribbean (Guadeloupe, Martinique, Saint Barthélemy, St. Martin)	Yes (2018)	Report	To improve the role of the State and its services without neglecting the challenge of associating and coordinating stakeholders (communities and inter-municipal authorities) according to their competence and their levers of action.	Early warning and event anticipation. Forecasting, monitoring and resources. Public information and instruction.
Guadeloupe (France)	Yes (2017)	Removal guidelines	To recall the best practices for collecting Sargassum seaweed for the technical services of local authorities and the green and blue patrollers in charge of cleaning beaches and bays from Guadeloupe.	Removal/clean-up best practice.
St Martin (France)	Yes (2020)	Removal guidelines	To remind of the best practices for collecting Sargassum seaweed for cleaning beaches.	Background information. Removal/clean-up best practice.
Puerto Rico (USA)	Yes (2015)	Management plan	None explicitly stated.	Removal/clean-up best practice. Policy's legality and stakeholders.
US Virgin Islands (USA)	No	N/A	N/A	N/A
		Sovereign states		
Antigua and Barbuda	Yes (2017)	Removal guidelines	None explicitly stated.	Removal/clean-up best practice.
Bahamas	No	N/A	N/A	N/A
Barbados	Yes (2021)	Strategy	To assist the government and people of Barbados in being resilient to threats from influxes of sargassum seaweed, turning the potential threats, when possible, into adaptive opportunities for sustainable development (social, economic, environmental).	Management institutions and authorities. Economic opportunities. Influx event management.

Table 2. *Cont.*

Territory	Policy (Year)	Type	Aim	Focus
Belize	No	N/A	N/A	N/A
Cuba	No	N/A	N/A	N/A
Dominica	Yes (2019)	Management plan	To address the negative impacts of the sargassum influx while taking advantage of the various positive opportunities it presents.	Consultation. Background information. Short-term and long-term strategies.
Dominican Republic	No	N/A	N/A	N/A
Grenada	Yes (2017)	Management plan	None explicitly stated.	Identifying who is responsible for what, establishing a legal base.
Haiti	No	N/A	N/A	N/A
Jamaica	Yes (2015)	Strategy	To define measures to respond to the abnormal accumulation of sargassum on the Island's shoreline through national public sensitisation, community mobilisation and clean-up activities.	Background information. Impacts. Influx event management. Budget and stakeholders.
Saint Lucia	Yes (2017)	Management plan	None explicitly stated.	Blueprint for a future proposed strategy. Sargassum innovation opportunities.
Saint Kitts and Nevis	Yes (2017)	Management plan	To ensure the protection and conservation of coastal resources and the sustainability of marine resources.	Sargassum background information. Sargassum impacts. Stakeholders. Relevant legislation. Removal/clean-up best practice.
Saint Vincent and the Grenadines	Yes (2018)	Management plan	None explicitly stated.	Location-specific experiences. Establishes governance set-up Removal/clean-up plan.

Table 2. *Cont.*

Territory	Policy (Year)	Type	Aim	Focus
Trinidad and Tobago	Yes (2016)	Management plan	To foster a coordinated approach to the problem involving key sectors, including an early warning component, communication mechanism and strategy for clean-up and disposal/utilisation of plant material.	Background information. Early warning system. Communications. Influx event management.

* Not included in further analysis; policy/guideline documents not available for analysis. † Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten.

A qualitative thematic analysis was used to examine the sixteen sargassum policy documents, drawing from the adaptation activity typology developed by Biagini et al. [13] and Klein et al.'s [14] categorisation of key opportunities and constraints in climate change adaptation (see Tables 3 and S2). While we consider adaptation constraints in this work, hard limits to adaptation are not part of this analysis because they are difficult to capture and subjective [14]. Across all three analyses, consideration is also given to sargassum adaptation activities, opportunities and barriers that may not be covered by these existing climate change-focused assessment frameworks.

Table 3. Typologies that frame adaptation activities.

Typology	Category
Typology of adaptation [13]	Capacity building Management and planning Practice and behaviour Policy Information Physical infrastructure Warning or observing system "Green" infrastructure Financing Technology
Adaptation opportunities [14]	Awareness raising Capacity building Tools Policy Learning Innovation
Adaptation constraints [14]	Physical Biological Economic Financial Human resource Social and cultural Governance and institutional

3. Results

3.1. Overview of Sargassum Adaptation Policy and Practice Across Territories

By 2021, most states and territories in the study area had produced some kind of policy document to guide the management of sargassum influxes. Nevertheless, there are five sovereign states and one territory for which no policy was identified (Bahamas, Belize, Cuba, Dominican Republic, Haiti and the US Virgin Islands) and twelve territories depending solely on a policy produced for a group of territories (Anguilla, Bermuda, British Virgin Islands, Montserrat, Turks and Caicos, Aruba, Curaçao, Saba, Sint Eustatius, Sint Maarten, Martinique and Saint Barthélemy). All things being equal, SNIJs are slightly more likely not to have a territory-specific policy than independent states (see Figure 1). Table 2 summarises the state and scope of policies, with policy types ranging from removal guidelines (generally focused on beach clean-up actions) to management plans and strategies (with consideration beyond clean-ups and often for multiple years), while Figure 2 provides an overview of the key metrics of this analysis: adaptation types, opportunities and constraints.

(a). Subnational Island Jurisdictions (SNIJs) **(b). Sovereign states**

Figure 1. Percentage of thirty-two Wider Caribbean Region Island sovereign states and SNIJs with some form of sargassum policy present by 2021.

The common adaptation types in Figure 2a are revealing not only in what the policies focus on but also in the notable absence of adaptation considerations. Almost all policies include capacity-building elements, and most also contain policy and information adaptation actions. There is no inclusion of green infrastructure to adapt to sargassum; the authors are also unaware of any existing green infrastructure technologies that have been developed to do so. Technology and (physical) infrastructure feature little in the adaptation policies, suggesting that despite a focus on innovation opportunities (Figure 2b), these innovations may not yet be coming to fruition as applicable adaptation practices. Other adaptation types and opportunities are almost exclusively focused on the valorisation of sargassum through sale as a product or the development of market potential. Even when the greater total number of sovereign state policies is taken into account, sovereign state policies appear to encompass a wider range of adaptation types, including management and planning, financing and technology. Policy and warning or observing systems are where SNIJs proportionally dominate in terms of adaptation types.

Despite a significant number of policies containing information and learning, only half identified warning/observation systems as part of their plan, and only four identified opportunities to develop adaptation tools. There was little consideration for sargassum in terms of risk and disaster risk reduction—hazard, exposure, vulnerability and uncertainty—and only one policy touched on insurance. The more recent policy from Barbados explicitly raises the issue of ensuring insurance covers sargassum: "where insurance is available as a mitigation measure, [ensuring] that premiums are paid up and that the coverage is adequate to cover loss and damage" [33].

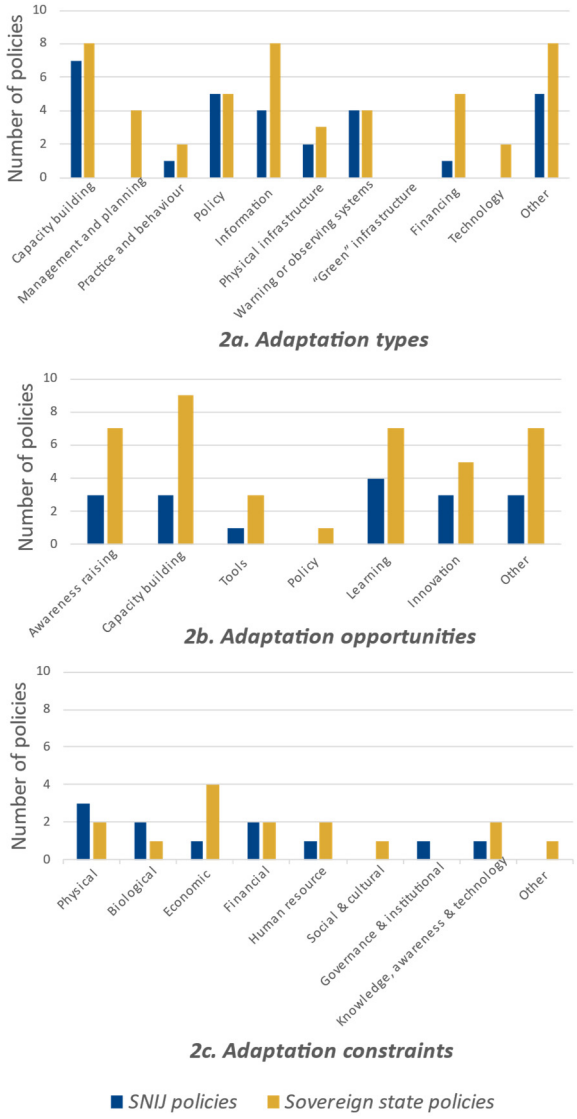

Figure 2. Summary of the number of policies (nine from sovereign states and seven from SNIJs) containing adaptation types [13], opportunities and constraints [14].

Many of the policies remain limited in scope, and whilst the emphasis on capacity building and information is an important and worthwhile beginning to adaptation, they lack a recognition of the diversity of actions that support effective adaptation. Figure 2 also demonstrates the emphasis of policies on actions across a range of adaptation types over any consideration for opportunities or constraints. As is evident from Figure 2c, although several opportunities and constraints to adaptation were identified in policies, neither opportunities nor constraints were as widely included in policy documents as actions. Sovereign state policies appear to have greater consideration for adaptation opportunities than policies from and for SNIJs, even when the different number of policies is considered. While SNIJs may have higher GDPs/capita than sovereign states in the Caribbean (see Table 1), this does not appear to be indicative of the rigour of adaptation policy with regard to the emergent threat of sargassum. SNIJs may have sargassum adaptation policies, but they are generally much more limited in scope than those of sovereign states.

3.2. Variation in Adaptation Policies Between Territories

All states and territories encompassed in this study are either SIDS or SNIJs or both [22,34], but even within smallness, there are gradations of size, both according to land

area and population. Being small in terms of population appeared, if anything, to increase the likelihood of having a sargassum-specific management policy. Whilst only half of the studied territories with populations over one million have a policy, the majority of those with smaller populations have a policy. There does not appear to be a similar correlation between wealth (GDP per capita) and policy absence/presence; both the wealthiest (Bermuda) and poorest (Haiti) territories considered in this study lack a sargassum adaptation policy, whereas other relatively wealthier (e.g., Cayman Islands, Aruba and Sint Maarten) and relatively poorer (e.g., Dominica, Jamaica, Saint Vincent and the Grenadines) territories have sargassum adaptation documents. None of the largest territories, according to land area (>100,000 sq km), have sargassum-specific adaptation policies, while twenty-one out of twenty-seven smaller territories have policies. The smaller the size of an area, the greater its boundaries, and thus, for islands, coasts are relative to their sizes. Those states with proportionally greater coastlines relative to their land area are thus also those more likely to have developed sargassum-specific adaptation policies by 2021.

Previous work has noted the possible role that regional organisations could play in coordinating policies and practices around sargassum [19]; however, currently, there does not appear to be a relationship between membership in regional bodies and sargassum policy. There are Caribbean Community (CARICOM), the Organisation of Eastern Caribbean States (OECS) and the Association of Caribbean States (ACS) members that have sargassum-specific policies and those that do not. However, over two-thirds (fifteen) of the twenty-one study territories that have endorsed the Caribbean and North Brazil Shelf Large Marine Ecosystems Strategic Action Programme (CLME+) have sargassum-specific policies, while only five territories that have endorsed CLME+ do not have policies. The CLME+ strategic action programme identifies priorities for improving the transboundary governance and management of shared living marine resources, which are agreed upon by endorsing countries [35]. It is, therefore, potentially well-placed to coordinate sargassum adaptation among countries and possibly facilitate best practices in the development and delivery of adaptation policies.

3.3. Use Opportunities Identified for Sargassum Adaptation

The narrative on adaptation to sargassum influx events remains mixed. The potential and experienced threats of sargassum are significant and severe, with negative social-ecological impacts on nearshore and onshore activities and ecosystems. Nevertheless, there is also an increasing interest in the opportunities and benefits of sargassum, which is evidenced in many of the policies analysed. In Table 4, the potential and actualised opportunities and benefits that are proposed by sargassum adaptation policies in the Caribbean are outlined. As the examples demonstrate, these adaptations are not all state-led, with Algas Organics in St. Lucia exemplifying private, entrepreneurial adaptation opportunities generated by sargassum influxes. Currently, the adoption of many of these opportunistic adaptations requires private sector buy-in; there is little state guidance or resource support outlined across sargassum adaptation policies. Furthermore, not all policies identify opportunities, with the management plan for Bonaire (The Netherlands) and removal guidelines for Guadeloupe (France) containing no explicit consideration of potential benefits or opportunities generated by sargassum influx events.

Table 4. Overview of proposed and potential opportunities and benefits in sargassum-specific adaptation policies.

Opportunity or Benefit	Policies	Example from Documents
Adobe bricks or construction	Barbados, Dutch Caribbean (Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten)	Construction of houses.
Agriculture	Barbados, French Caribbean (Guadeloupe, Martinique, Saint Barthélemy, St. Martin), Saint Lucia	Maintain soil moisture and plant growth.
Antifouling coatings	Barbados	No examples provided
Beach or sand dune nourishment	Antigua and Barbuda, Barbados, Cayman Islands, Dutch Caribbean (Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten), Grenada, Jamaica, Puerto Rico (USA), St. Kitts and Nevis, Trinidad and Tobago, Saint Vincent and the Grenadines, Saint Lucia	Sargassum burial on the beach or dunes to fertilise beach vegetation. Enhanced plant germination.
Biofuel	Barbados, Dominica, Dutch Caribbean (Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten), French Caribbean (Guadeloupe, Martinique, Saint Barthélemy, St. Martin), Jamaica, Saint Lucia, Trinidad and Tobago	Combustion of sargassum to replace bagasse.
Biomass	Dominica	No examples provided
Bioplastics	Dutch Caribbean (Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten), French Caribbean (Guadeloupe, Martinique, Saint Barthélemy, St. Martin)	Natural filler in the manufacture of plastic.
Biosorbent	Barbados, Dominica, Dutch Caribbean (Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten), Saint Lucia	Removal of heavy metals in polluted water.
Biostimulant or fertiliser	Antigua and Barbuda, Dominica, Dutch Caribbean (Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten), Grenada, Jamaica, St. Kitts and Nevis, Saint Lucia, Trinidad and Tobago	Biostimulant made from collected sargassum.
Charcoal briquettes	Dominica, Dutch Caribbean (Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten)	Ground into a powder and mixed with other sources.
Chemical compounds for pharmaceuticals/food supplements	Barbados, Dominica, Dutch Caribbean (Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten), Saint Lucia, Trinidad and Tobago	In vitamins or medical treatments
Clothing or footwear	Barbados	No examples provided
Cosmetics	Barbados, French Caribbean (Guadeloupe, Martinique, Saint Barthélemy, St. Martin)	Extraction of alginate.
Direct spreading, mulch or compost	Antigua and Barbuda, Barbados, Cayman Islands, French Caribbean (Guadeloupe, Martinique, Saint Barthélemy, St. Martin), Grenada, Jamaica, Puerto Rico (USA), Saint Lucia, St. Martin (France), Saint Vincent and the Grenadines, Trinidad and Tobago	Wash salt out and mix with manure and soil.

Table 4. *Cont.*

Opportunity or Benefit	Policies	Example from Documents
Electrochemical industry	Barbados	No examples provided.
Fish types	Dutch Caribbean (Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten), St. Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines	Different fish types in offshore sargassum: mahi-mahi, kingfish and amber covali.
Food industry	Barbados, Saint Lucia	Salads, soups and curry.
Fungicide	Trinidad and Tobago	No examples provided.
Livestock, poultry or fish feed	Dominica, Grenada, Jamaica, Puerto Rico (USA), St. Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago	Supplementary feed for cattle, horses and sheep.
Lubricants, surfactants or adhesives	Barbados	No examples provided.
Paper	Barbados	No examples provided.
Other solutions	Antigua and Barbuda, Barbados, Saint Vincent and the Grenadines, Trinidad and Tobago	Organic matter. Community-based micro-industries. Local enterprises. Environmental restoration.
Shoreline stability	Antigua and Barbuda, Cayman Islands, Grenada, Jamaica, Puerto Rico (USA), St. Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago	Shoreline stabilisation. Combat erosion. Dune stability. Sand retention.
Soap	Dutch Caribbean (Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten)	Sargassum soap.
Take-away containers	Dutch Caribbean (Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten)	With cassava, starch and banana fibre.

3.4. Limitations of Existing Adaptation Policies

The absence of discussion of constraints in policies should not be assumed to mean a lack of them; it could also be indicative of a lack of consideration for longer-term constraints to adaptation. Table 5 further exposes the emphasis of most policies on adaptation actions and opportunities, with a number of policy documents not discussing constraints whatsoever (Cayman Islands, Guadeloupe, Puerto Rico, Grenada, Jamaica, Saints Kitts and Nevis) and multiple identifying only one or two constraints. Unsurprisingly, territories with removal guidelines (underlined in Table 5), as opposed to strategies/plans, generally covered fewer types of adaptation and rarely considered opportunities or barriers. Removal guidelines, as the name implies, have a much more limited scope than sargassum management plans and policies.

Table 5. Analysis of sargassum adaptation policies.

State/Territory	Adaptation Typology	Adaptation Opportunities	Adaptation Barriers
Cayman Islands (UK)	Capacity building Policy Other	Not discussed	Not discussed

Table 5. *Cont.*

State/Territory	Adaptation Typology	Adaptation Opportunities	Adaptation Barriers
Dutch Caribbean (Aruba, Bonaire, Curaçao, Saba, Sint Eustatius, Sint Maarten)	Capacity building Policy Information Physical infrastructure Warning/observing systems Other	Awareness raising Capacity building Learning Innovation Other	Physical Biological Economic Financial Governance Knowledge
Bonaire (Netherlands)	Capacity building Practice and behaviour Information Physical infrastructure Warning/observing systems Other	Capacity building Learning Innovation Other	Physical Financial Human resources
French Caribbean (Guadeloupe, Martinique, Saint Barthélemy, St. Martin)	Capacity building Policy Information Warning/observing systems Financing Other	Awareness raising Capacity building Tools Learning Innovation Other	Physical Biological
Guadeloupe (France)	Capacity building Policy	Not discussed	Not discussed
St Martin (France)	Capacity building	Not discussed	Not discussed
Puerto Rico (USA)	Capacity building Policy Information Warning/observing systems Other	Awareness raising Learning	Not discussed
Sovereign states			
Antigua and Barbuda	Capacity building Information Other	Capacity building Learning Innovation Other	Economic Knowledge
Barbados	Capacity building Management and planning Practice and behaviour Policy Information Physical infrastructure Warning/observing systems Financing Other	Awareness raising Capacity building Tools Learning Innovation Other	Biological Economic Financial Human resources
Dominica	Capacity building Information Warning/observing systems Technology Other	Awareness raising Capacity building Policy Learning Innovation Other	Physical Economic Human resources Knowledge
Grenada	Capacity building Policy Other	Awareness raising Capacity building Other	Not discussed

Table 5. *Cont.*

State/Territory	Adaptation Typology	Adaptation Opportunities	Adaptation Barriers
Jamaica	Capacity building Management and planning Information Financing	Awareness raising Capacity building Learning Other	Not discussed
Saint Lucia	Capacity building Management and planning Policy Information Physical infrastructure Warning/observing systems Financing Technology Other	Awareness raising Capacity building Tools Learning Innovation Other	Economic Financial
Saint Kitts and Nevis	Capacity building Management and planning Policy Information Other	Awareness raising Capacity building Learning	Not discussed
Saint Vincent and the Grenadines	Capacity building Practice and behaviour Policy Information Financing Other	Capacity building	Physical
Trinidad and Tobago	Capacity building Information Physical infrastructure Warning/observing systems Financing Other	Awareness raising Capacity building Tools Learning Innovation Other	Social and cultural

Typology of adaptation from [13,14]; see Table 3 for details. Underlined territories are those with removal guidelines as opposed to a management plan/strategy.

The policies with the greatest breadth of adaptation types identified are generally either sovereign states (e.g., St. Lucia and Barbados) or documents produced by a territorial administrative body (e.g., the French Ministry of Higher Education, Research and Innovation and Dutch Caribbean Nature Alliance). Whilst by SNIJ territory or sovereign state, the number of adaptation types, opportunities and barriers identified are generally comparable, the most notable difference remains the absence of an island-scale policy for multiple SNIJs (Aruba, Curaçao, Saba, Sint Eustatius, Sint Maarten, Martinique, Saint Barthélemy and the US Virgin Islands) and only a few states (Bahamas, Belize, Cuba, Dominican Republic and Haiti); half of SNIJs have no island-specific policy, while around one in three sovereign states have no island-specific policy.

Other state and territorial policies on hazards, climate change and environmental management were also examined for their inclusion of sargassum, but very few consider sargassum influxes. In Figure 3, we examine this range of policies and simply ask the following question: is sargassum mentioned? Most policies do not mention sargassum, with little consideration given to climate change adaptation plans and invasive species plans. Both of these absences are surprising, as sargassum policies themselves frame the threat as being an issue of invasion (Dominica, Dominican Republic, Dutch Caribbean, Jamaica, St.

Vincent and the Grenadines, St. Lucia, Trinidad and Tobago), with possible links to climate change (Antigua and Barbuda, Barbados, Cayman Islands, Dominica, Dominican Republic, Dutch Caribbean, French Caribbean, Jamaica, St. Lucia and St. Martin).

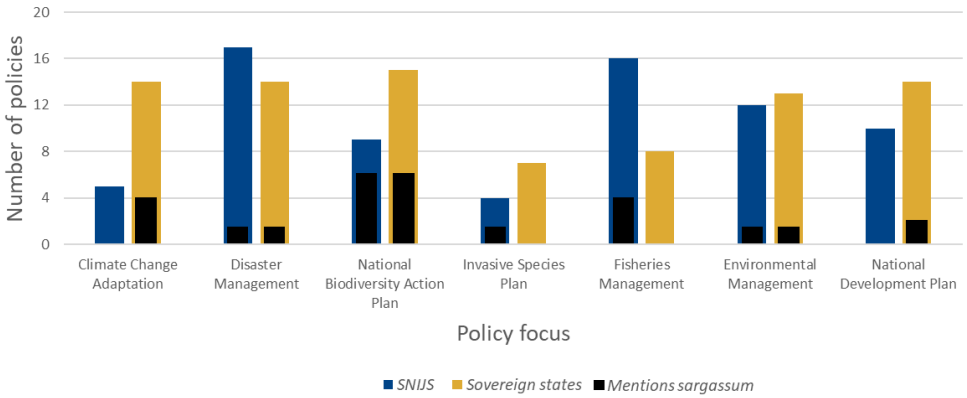

Figure 3. Relevant policy documents identified for thirty-six case states and territories, as well as the number that mention sargassum.

Sargassum was most often mentioned in biodiversity action plans, with six sovereign and SNIJ policies each mentioning sargassum. Four sovereign state policies on climate change adaptation mention sargassum, and no SNIJ policies mention it; four fishery management policies from SNIJs mention sargassum, while no sovereign state policies mention it. Proportionally, sargassum was more frequently present in sovereign state environmental and climate change policies, suggesting that adaptation to sargassum is being better integrated across policy arenas in sovereign states than in non-sovereign territories. Nevertheless, as Figure 3 highlights, sargassum is generally not integrated into other policies, with the only exception being biodiversity action plans among SNIJs (where six out of the nine identified biodiversity action plans included sargassum).

4. Discussion

An analysis of sargassum adaptation policies in the WCR from 2011 to 2021 highlights the challenges faced by SIDS in adaptation, with a significant number of states and SNIJs still having no sargassum-specific policy despite the severe impacts on coastal communities. Of existing sargassum policies, many remain limited in scope, none have passed through the legislature, and few have clearly identified resources with which to enact the policy. Nevertheless, beyond providing another reminder of the barriers and limitations to adaptation faced by SIDS, this analysis of management policies identifies several key lessons on adaptation to emergent threats more widely, for which there remains little understanding across scales and sectors. We reflect on four key lessons that the Caribbean experiences of sargassum offer to adaptation studies.

4.1. Enabling Rapid Adaptation to Emergent Threats

The rate of policy development in response to the sudden growth in the frequency and severity of sargassum influx events experienced in Caribbean territories since 2011 highlights the capacity of SIDS to develop national strategies for emergent threats. Sargassum was more frequently included in other environmental and climate change policies by sovereign state policies, suggesting that SNIJs have had greater difficulties integrating sargassum across policy arenas. Environmental mainstreaming, the integration of one environmental policy instrument into more general policy planning and implementation [36], could support integrating adaptation to sargassum into everyday decision-making as it becomes increasingly clear that sargassum influx events are here to stay. Similarly to climate

change adaptation in Caribbean SIDS [20], financing often remains a key constraint in adaptation to sargassum nationally. Our study focused on national-scale adaptation policies, and policies do not reveal who is talking to who and do not capture what is occurring in practice [37]. Nevertheless, within those policy documents, the role of microeconomic players (households, small businesses and communities) in driving this rapid adaptation is apparent; individual businesses are often at the forefront of removal processes (i.e., national guidelines directed at individuals and communities who would be conducting the clean-up in practice), and many of the opportunities to use, valorise and commercialise sargassum are similarly posed and inspired by independent actions undertaken through entrepreneurial action at the small scale. Coastal climate change adaptation work is often focused on questions of coastal infrastructure and remains "defence"-orientated, i.e., how to "protect" from the sea [38,39]. But in the case of responding to sargassum influx events in the Caribbean, the role of (1) locally driven ideas and practices for adaptation and (2) identifying opportunities that can be derived from extreme changes are shown to be prevalent and are leading the rapid adaptation process.

4.2. The Role of the Science–Policy Interface in Rapid Adaptation

To minimise the negative impacts of the influx events, sargassum adaptation and research efforts should be coordinated across stakeholders [5]. Yet there remains a lack of evidence-based policymaking culture in the Caribbean ocean governance context [40,41]. Sargassum rarely features in wider hazard, environmental and climate change policies, suggesting that, to date, the emergent threat is largely managed in isolation from other social-ecological challenges. There are some well-established science–policy mechanisms in the Caribbean region for environmental and climate change issues. The Caribbean Community Climate Change Centre ("CCCCC") plays an important role in funding local adaptation measures and facilitating experience-sharing and cooperation among Caribbean SIDS [26]. The Centre for Resource Management and Environmental Management (CERMES), a department of the University of the West Indies, has produced best-practice management briefs [42] and organised sargassum symposia to bring together researchers, innovators, and policymakers across the region [19]. There are many positive indications of established trust and existing relationships among sectors in the Caribbean region for adaptation, but there remains scope for science to be integrated into adaptation policies, and there is a critical role in facilitating communication, trust and relationship-building for organisations such as the CCCCC and CERMES. Establishing effective communication and trust in the science–policy interface for ocean governance may be further complicated by the transboundary nature of ocean challenges, such as sargassum influxes, but the complex governance required to address such threats and changes also increases the importance of effective and clear communication to inform evidence-based decision-making [41].

4.3. Regional Mechanisms to Support Adaptation

Adaptation to emergent threats, such as those being driven by climate change, requires action at multiple levels of governance to increase participation and coordination across levels of decision-making [43]. Whilst our work does not, per se, explore governance across scales of the SNIJs studied, very few had both a state- and island-based policy for sargassum (just Bonaire, Guadeloupe and St. Martin). Similarly, while some regional organisations have produced policies and reports for sargassum adaptation [44,45], there remains a notable absence of regional governance for sargassum influxes. The lack of effectiveness of regional organisations in coordinating adaptation projects for SIDS has been previously noted [46]; regional bodies can play a critical role in overcoming information-deficit challenges and building territory-level capacity. In the case of sargassum adaptation,

research and capacity-building are actions that many policies focus on, suggesting that there is momentum that regional organisations could use to build and support.

4.4. From Policy Goal to Practice

Few of the policies reviewed in our analysis had clearly identified sources of funding; outlining responsible departments and bodies was the most significant resource policies tended to outline. The lack of resources in SIDS for sargassum adaptation is not surprising and is well documented for climate change adaptation generally [14,23]. Whilst our review focused on policy documents, within those documents, the progress of private (household and business) and local (community) adaptations to sargassum was often observed through actions including local responses to sargassum influx events and the valorisation and commercialisation of sargassum seaweed. Individuals and small businesses are often key drivers of the response to, management of and valorisation of sargassum; however, there appears to be limited support (guidance and resources) to increase the impact of these localised adaptations. Basic support from government bodies can further endorse such "microeconomic" adaptations, with interventions such as informational support being a commonly applied adaptive support mechanism in climate change adaptation more widely [47]. Despite many examples of locally driven ideas and practices, our analysis highlights that many best-practice elements of disaster risk management (i.e., Hyogo Framework, Sendai Framework) remain absent from existing sargassum adaptation policies. We recommend that future development of adaptation policy for emergent coastal changes take greater account of how government bodies and interventions can support active and commercial adaptation options.

5. Conclusions

There is an increasing number of examples of adaptations to actual and anticipated climate change on the coast, but we know much less about adaptation processes for emergent threats. Climate change adaptation studies of the coast remain largely centred on questions of sea level rise, extreme weather events and coastal flooding. Few studies have considered how adaptation to emergent threats may unfold in the face of new hazards or indirect, transboundary and long-distance impacts of climate change. We analysed the variation in policies for sargassum management in the Caribbean, adaptations to a recurring seaweed influx event rarely experienced prior to 2011 but regularly since then, to identify lessons for rapid adaptation to emergent environmental challenges generally.

In ten years, the majority of the WCR islands have gone from experiencing a totally new hazard to better understanding it, researching what to do, trying to determine what works best, and coming up with initial guidelines. The policy response has been strikingly fast, and there are already many examples of stakeholders involved across scales, from regional symposia to individual entrepreneurial efforts. We conclude that despite the inherent vulnerability of SIDS to climate change, coastal hazards and emergent threats, in the context of the WCR, there are established bodies to support rapid coastal adaptation (i.e., CERMES and CCCCC) and an entrepreneurial and open mindset to consider and test opportunities from threats. Indeed, smaller territories may be more likely to prioritise adaptation because of the greater relative exposure of coastlines to this emergent threat. Nevertheless, if areas continue to undergo long-term shifts away from one industry and toward another in response to sargassum influxes, they may require/involve social, livelihood and legal change [48], beyond that identified in this policy analysis. The case of adaptation to sargassum in the WCR thus shows us that while private adaptations to emergent threats may be quicker to develop and execute, longer-term, larger-scale adaptations will depend on evidence-based, widely supported policies with clear avenues of funding.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/phycology5010002/s1: Table S1: Themes and codes for document analysis, adapted from [13,14]. Table S2: Overview of analysed sargassum adaptation documents.

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