Applying Hazard Risk Assessment and Spatial Planning Tools to Sargassum Inundations in the Eastern Caribbean Small Island States as a Basis for Improving Response

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SargAdapt Project Report

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This technical report is intended to act as a valuable resource for the wider sargassum stakeholder community as well as to inform other aspects of the SargAdapt project including assessment of the vulnerability of ecosystems and coastal communities to sargassum impacts.

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TABLE OF CONTENTS

ABSTRACT

Episodic Influxes of pelagic sargassum into the Caribbean often result in inundation of coastlines with significant negative impacts to the environment, society and the economy. As such, sargassum inundations qualify as a coastal hazard. Spatial variation in sargassum inundations have important implications for management response to this hazard, including alleviation of associated negative impacts and/or harvesting sargassum for valorisation. However, there is no systematic monitoring of sargassum inundations and thus a lack of data on the spatial and temporal distribution and extent or magnitude of this hazard. In this study we apply, in combination, the tools of hazard risk response and spatial planning to the problem of sargassum inundations for the first time, to assess the efficacy of this approach. We use secondary data in the form of publicly available remotely sensed images (from Google Earth) to develop sargassum inundation hazard maps for each of the five project countries in the Eastern Caribbean (Barbados, Dominica, Grenada, St Lucia, and St Vincent and the Grenadines). We also use spatially explicit secondary data on important assets within three categories (fisheries, tourism, and coastal ecosystems) obtained from a variety of sources to map assets and subsequently overlay with sargassum inundation hazard maps to examine exposure of different assets to this hazard. Notwithstanding the challenges and limitations of available secondary data, clear spatial patterns still emerged from the relatively low cost, simple outputs that demonstrate the usefulness of this approach in providing a solid basis for systematic and strategic planning to improve the current efforts and outcome of sargassum management initiatives.

1. INTRODUCTION

1.1. Problem Definition

Sargassum seaweed has been arriving in unprecedented quantities on Caribbean and West African shorelines since 2011 (Franks et al. 2012; Franks, Johnson, and Ko 2016; Smetacek and Zingone 2013). These “sargassum influxes” into the region lead to “inundations” along coastlines, with significant negative impacts across the environment, society and economy that have been well described (United Nations Environment Programme - Caribbean Environment Programme et al. 2021). Sargassum influxes, inundations and the associated impacts vary in both time and space. The temporal variation in sargassum influxes is complex and is the subject of extensive research, especially for the purposes of forecasting (Oxenford et al. 2021). The spatial variation in sargassum influxes and the associated inundations and impacts has implications for management response as well as harvesting sargassum for valorisation. Here we focus on the implications of, and the challenges posed by, the variation in space over time.

The impacts of sargassum inundations may be expected to vary in space as a result of the following factors:

- Sargassum inundations themselves are not uniformly distributed in space. For example, the Eastern Caribbean is on the frontline of sargassum influxes from the source region into the Caribbean. In general, eastern or windward coastlines tend to receive greater volumes of sargassum than western or leeward coastlines.
- The biophysical characteristics of the coastline influence the nature and type of impacts from sargassum inundations. For example, depending on shoreline morphology and dynamics, sargassum may decompose in the nearshore fouling water quality, whereas some locations experience high piling of sargassum onshore; some locations may experience both.

- The socio-economic characteristics of the coastline area also influence the nature and type of impacts from sargassum inundations. For example, impacts on tourism occur where tourism assets are exposed; not every tourism asset is exposed to sargassum inundations and not every exposed location contains tourism assets.
- The Caribbean as a region is complex and diverse. There is a mix of continental land masses and small islands, along with considerable variation in size and level of development of states across the region. This translates to considerable variability in 1) available capacity and resources to respond to the issue and 2) environmental conditions and logistics that affect the response. For example, the high energy sea conditions and narrow shallow shelf typical of the windward coasts of Eastern Caribbean islands present a very different (and more challenging) environment for alleviating sargassum inundations than the more sheltered sea conditions typical of the Western Caribbean (Central America) where there is a wide shallow shelf, and the coastline is typically protected by offshore barrier reefs.

Small i=Island Developing States (SIDS) are especially vulnerable to external shocks and struggle to mobilise the resources and/ or capacity to mount an effective response. Small islands have generally considerably higher ratios of coastline length to land area than continental states, which amplifies their vulnerability to coastal problems (Nunn et al. 1999). Environmental conditions and response logistics in SIDS are generally very different from those of continental states. Fragmented coastlines with small bays and pocket beaches on exposed windward coastlines in the Eastern Caribbean present very different conditions for clearing sargassum wrack from beaches, using booms to hold-back sargassum or harvesting sargassum, than the long expanses of beach more typical of the Western Caribbean continental countries. Currently, there is a lack of coordinated or efficient strategic planning to tackle the problem of sargassum inundation (UNEP-CEP et al. 2021). For SIDS especially, strategic planning is critical to maximise the impact of the response and make effective and efficient use of limited resources. However, the same resource limitations also limit monitoring and data collection that would inform response planning. As a consequence, there is also a lack of consistent and systematic monitoring data on the spatial and temporal distribution and extent or magnitude of sargassum inundations (UNEP-CEP et al. 2021), further compounding the challenge.

1.2. Research Rationale and Objectives

In this research, we apply, in combination, the tools of **hazard risk response** and **spatial planning** to the problem of sargassum inundations. Sargassum inundations cause health impacts, social and economic disruption and environmental degradation, meeting the United Nations office for Disaster Risk Reduction (UNDRR) definition of a hazard (Table 1). The determinants of hazard risk are **exposure** and **vulnerability**, which are defined below (Table 1). Spatial planning can reduce hazard risk by influencing the exposure and/ or vulnerability of people and assets through changes in spatial development and spatial structure as illustrated in Figure 1 (McMillan, Birkmann, and Tangwanichagapong 2021).

Table 1. Terminology. Definitions are selected and adapted from various sources (IPCC 2012; UN-SPIDER 2022) for the purposes of this research

Hazard is a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Hazards may be single, sequential or combined in their origin and effects. Each hazard is characterized by its "location, intensity or magnitude, frequency, and probability.
Exposure the situation of people and tangible assets, such as infrastructure, housing, ecosystems, and production capacities, located in hazard-prone areas.
Vulnerability is the propensity or predisposition to be adversely affected. Vulnerability is multi-dimensional by nature, there being physical, social, economic and other factors in vulnerability. Examples include poor design and construction of buildings (physical), poverty or lack of education (socio-economic). The factors in vulnerability and means of measurement depend on what is being assessed (country, system, community, people, asset) and the scale at which it is being assessed.
Risk is the potential impact of the hazard event. Its determinants are exposure and vulnerability.
Impact is risk realised. For impacts to occur, by definition, the asset must be both exposed vulnerable when the hazard event occurs.

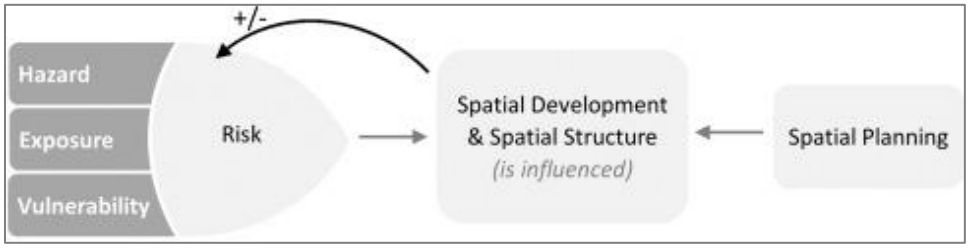


Figure 1. Schematic depiction of the relationship between climate risk and spatial planning, from McMillan, Birkmann, and Tangwanichagapong, 2021.

By definition (Table 1), a hazard is characterized by its location, intensity or magnitude, frequency, and probability. For spatial planning purposes, a hazard may be represented spatially by representing its intensity/ magnitude and frequency and/ or probability on a map of the study area, i.e., hazard mapping. By definition (Table 1), exposure refers to the situation of assets in the path of a hazard. Exposure may therefore be represented spatially by overlaying hazard mapping with mapping of the assets being considered.

The ultimate objective of this research is to test the application of combined hazard risk assessment and spatial planning as tools to support improved response planning for sargassum inundations. The geographic focus of the study is on five Eastern Caribbean SIDS – Barbados, Dominica, Grenada, St. Lucia and St. Vincent and the Grenadines (Figure 2). It is intended that the findings and outputs of this research will be useful to policy makers and technical officers involved in sargassum inundation response in the project countries. The use of the exposure and vulnerability concepts will facilitate unpacking the factors underlying the impacts of sargassum inundations and their variation in space. Assessing and mapping risk allows responders to make targeted interventions to reduce risk by reducing exposure and/or vulnerability, or to direct resources to alleviate impacts where they are most needed. As such, it is anticipated that this research will also be useful as a framework for replication across other countries in the Wider Caribbean that are similarly affected by sargassum inundations.

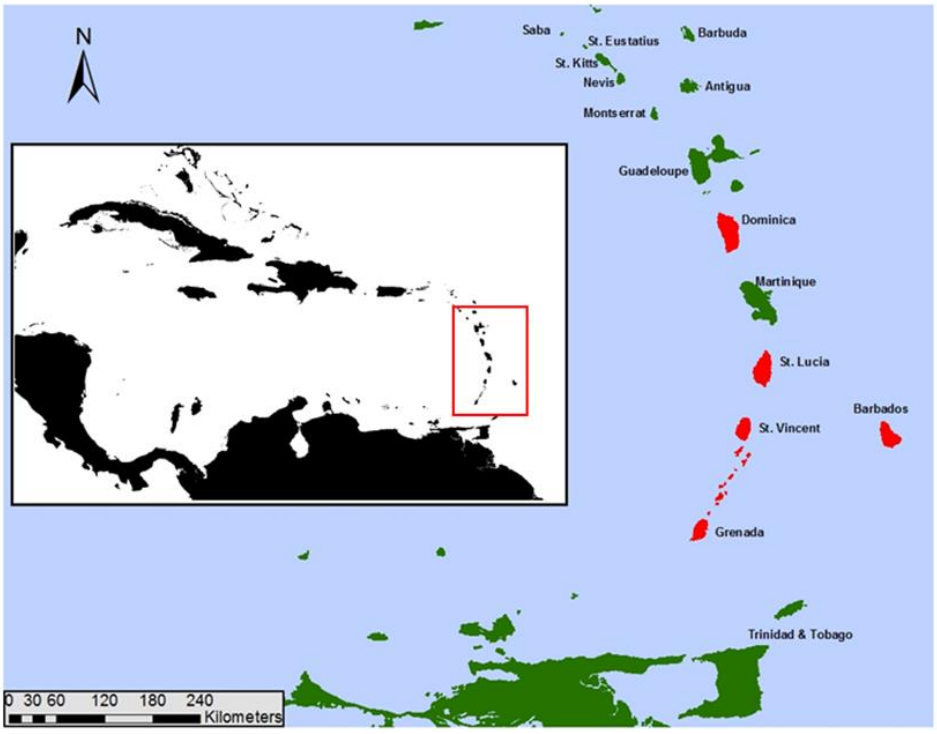


Figure 2. Map showing project countries

The focus of this phase of the research, as presented in this technical memorandum, is testing the application of the proposed approach by describing and mapping, at an island-wide scale (coarse resolution), the exposure of key asset categories to sargassum inundations for five Caribbean SIDS using available, secondary, indirect observations of sargassum in the nearshore, in the form of remotely sensed imagery. Evaluating vulnerability to sargassum inundations will be addressed in the next phase, building on this exposure assessment.

For mapping sargassum inundations as hazard, data availability is a major limitation. Informal observations provide some indication of the general pattern of sargassum inundations around each island; for example, it is generally known that eastern/windward coasts receive greater volumes of sargassum, and particular sites may be highlighted in the public consciousness as a result of impacts experienced. However, there is little to no formally collected data on inundations that systematically or directly quantifies the spatial distribution, magnitude or frequency of inundations. Predictive modelling for sargassum inundations at the scale of specific island coastlines does not currently exist. Given the paucity of standardised sargassum monitoring, we explored whether available secondary sources of information might indirectly include observations of sargassum inundations.

2. METHODOLOGY

2.1. Alignment with Existing National Policy and Planning

This research has been aligned to existing policy and planning frameworks where possible and where they exist. Of the project countries, Barbados has the most advanced coastal zone management (CZM) framework that incorporates spatial planning, and this has therefore been used as a model.

The approach of integrating risk management into spatial planning, including the selected definitions of exposure and vulnerability, is consistent with the approach taken in the development of Barbados' National Coastal Risk Information Planning Platform (NCRIPP).

The island-scale, coarse resolution exposure mapping makes use of 'coastal zone sub-areas (CZSAs)' modelled on the Barbados CZM planning framework, in which the entire coastal zone is sub-divided into eight coastal zone sub-areas (Figure 3), each with similar characteristics. A similar concept, termed coastal regions, is used in Belize's CZM Plan. The CZSAs are large scale spatial units about which it is possible to make useful generalisations for use in spatial planning. Only one other project country, St. Lucia, has an existing framework with coastal sub-regions. For the other three countries (Dominica, St. Vincent and the Grenadines, Grenada), it was necessary to delineate new coastal zone sub-areas for the purposes of this research as they did not otherwise exist.

Figure 3. Coastal Zone Sub-Areas of Barbados (CZMU 2022)

2.2. Hazard characterisation and visualisation

Publicly available remotely sensed imagery (Google Earth) timestamped between 2011-2021 was inspected to determine whether sargassum inundations could be observed. Each image was treated as a single observation, and the full collection of available images (2011 – 2021) was treated as a sample set of observations used to assess the frequency of inundations. Images showing sargassum inundations in the study area were extracted for closer inspection to assess inundation magnitude. To indicate magnitude, a qualitative exposure rating (high, medium, low) was developed. Representative images of each magnitude rating (Figure 4) were selected and used to guide the assessment. Frequency was determined as the rate of occurrence of inundation (of any magnitude) over the entire sample (i.e., the total number of observations/ images).

Figure 4. Representative images for the magnitude rating (low, medium, high) used in hazard mapping

Magnitude and frequency were assessed for each individual continuous beach or bay, as bounded by clearly visible headland features. The frequency of each magnitude of inundation (high, medium, or low) was calculated for each beach/bay. The frequency of inundation (of any magnitude) was also calculated for each CZSA. Note that the individual beach or bay as a 'spatial unit' is not uniform in size/length. Shoreline cliff areas were not assessed, as sargassum presence on these shorelines was challenging to see in aerial images particularly when inundation was low magnitude. The CZSA is the larger spatial unit, containing multiple individual beaches/bays, and varying proportions of beach and cliff shoreline.

The methodology was influenced by two significant limitations arising from the use of the Google Earth imagery to indirectly observe sargassum inundations: 1) not every image in the historic timeline available for each island covered the whole island and 2) the coastline is sometimes obscured by cloud cover. To partially overcome these limitations, a process was developed for inferring the presence/absence of sargassum at unobserved sites on any given date from the presence/absence at observed sites. This extrapolation was based on patterns observed in images on dates with full or majority coverage of the island. For each country, the sample size (n) is the total number of observations, including from complete images, partial images, and inferences. The sample size varies across the five countries, because there were more images available for some than others. Limitations are discussed further in Section 3.4.

The spatial distribution of magnitude and frequency of sargassum inundation (from 2011-2021) were plotted to produce a hazard map for each project country. Each hazard map layer shows the frequency of inundation occurrence for each CZSA by means of a graduated colour scale. For each individual beach or bay where inundations occur, a pie chart depicts the frequency of each magnitude of inundation (high, medium, low) as well as the frequency of no inundation. Alongside the maps, the frequency by magnitude of each individual beach site is also plotted as a stacked bar chart for convenient visual assessment. Maps and charts both indicate the sample size (n) for the country.

2.3. Asset mapping

For this study, assets of interest are those that are known to be both of significant value nationally and to be significantly impacted by sargassum inundations. On this basis, three asset categories were identified, namely: tourism, fisheries and coastal ecosystems. Table 2 provides an indicative list of assets in each category. Existing spatial datasets for Barbados, Dominica, Grenada, St. Lucia, and St. Vincent & the Grenadines were obtained from various sources, including Government departments, regional and global agencies, and datasets in the public domain to create the asset maps for each category. SargAdapt Project National Coordinators were enlisted to assist in acquiring asset data.

Asset maps are compiled from multiple secondary data sources. In some cases, asset mapping was limited by data availability. Not every asset identified for each category is represented for each country. The accuracy and/or completeness for each layer may vary.

Table 2. Assets

Asset Category	**Assets in each category**
Tourism	Airports
	Cruise ports, marina facilities, ferry operations, anchorages etc.
	Dive centres
	Dive sites, including reefs and shipwrecks
	Hotels/Resorts
	Recreational areas and attraction sites, including parks, surf breaks etc
Fisheries	Fish landing sites
	Fishing grounds
	Fish landings
Coastal Ecosystems	Coral reefs
	Mangroves, wetlands, swamps, salt ponds
	Sandy beach
	Seagrass
	River outlets
	Sea bird nesting areas/bird swamps
	Sea turtle nesting sites

2.4. Exposure Map Assembly and Validation

ArcMap version 10.8.2 was used to generate all of the maps. Data were obtained from different sources and as a result had different projected coordinate systems. To help with accuracy of overlaying the spatial data, a uniform geographic and projected coordinate system was used. The geographic coordinate system used for the maps was WGS 1984 and the projected coordinate system used was

WGS_1984_UTM_20_N_Zone for Dominica, Grenada, St. Lucia, and St. Vincent and the Grenadines and WGS_1984_UTM_21_N_Zone for Barbados.

Exposure maps for each of the three categories were assembled by overlaying sargassum inundation hazard maps with asset map layers from the categories identified. The exposure maps were used to qualitatively assess and describe the patterns of exposure of each asset category.

A validation workshop was convened to review the first drafts of hazard, asset and exposure maps. Participants comprised the national coordinators (one per country) for the SargAdapt project. The national coordinators had been selected in part for being knowledgeable of coastal resources and coastal zone management in each country. Through the workshop and subsequent follow up, national coordinators were asked to provide feedback as to whether 1) the hazard mapping was consistent with their informal observations, and 2) the clarity and readability of the maps was appropriate. They were also able to assist in filling data gaps related to asset mapping. Maps were updated with the feedback and input from this process.

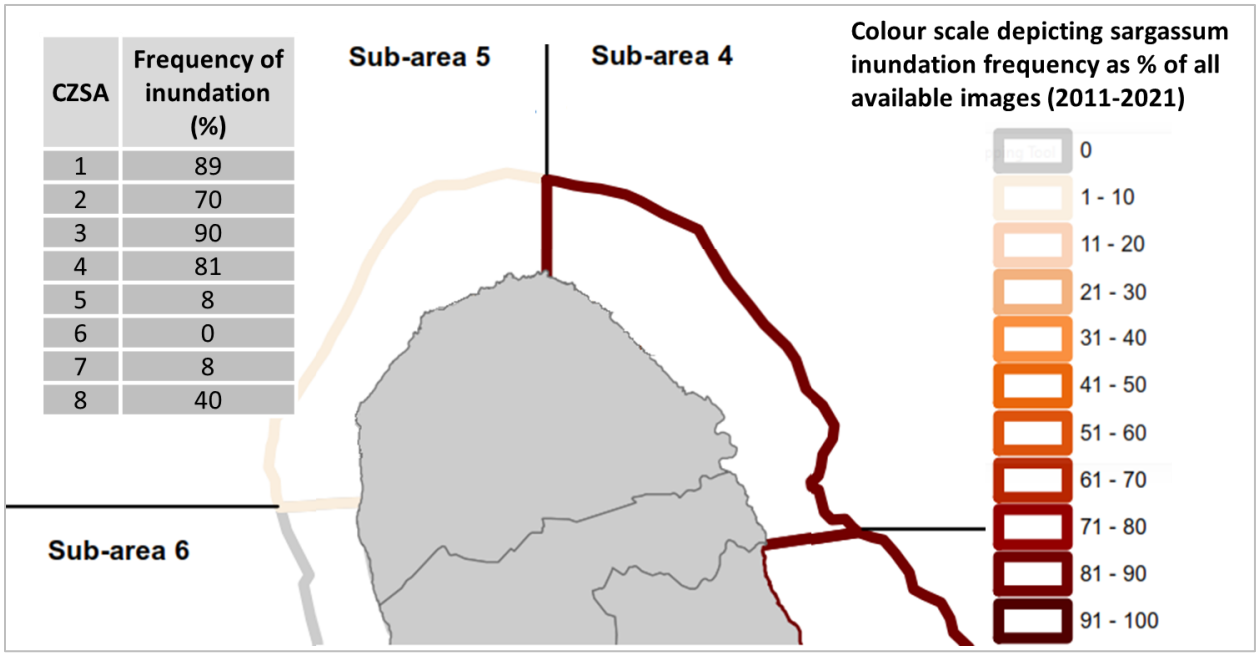
3. FINDINGS AND DISCUSSION

This section summarises the overall findings of applying a hazard risk assessment approach to sargassum inundations in the Eastern Caribbean Small Island Developing States and discuss the potential usefulness of this spatial planning tool for improving management response to the sargassum inundation issue.

The country results, giving detailed analysis, hazard maps and exposure maps for each of the three asset categories (tourism, fisheries, and coastal ecosystems) together with a description of the key features and observed patterns are given in Annex 1, separately for each of the five project countries.

3.1. Hazard Maps

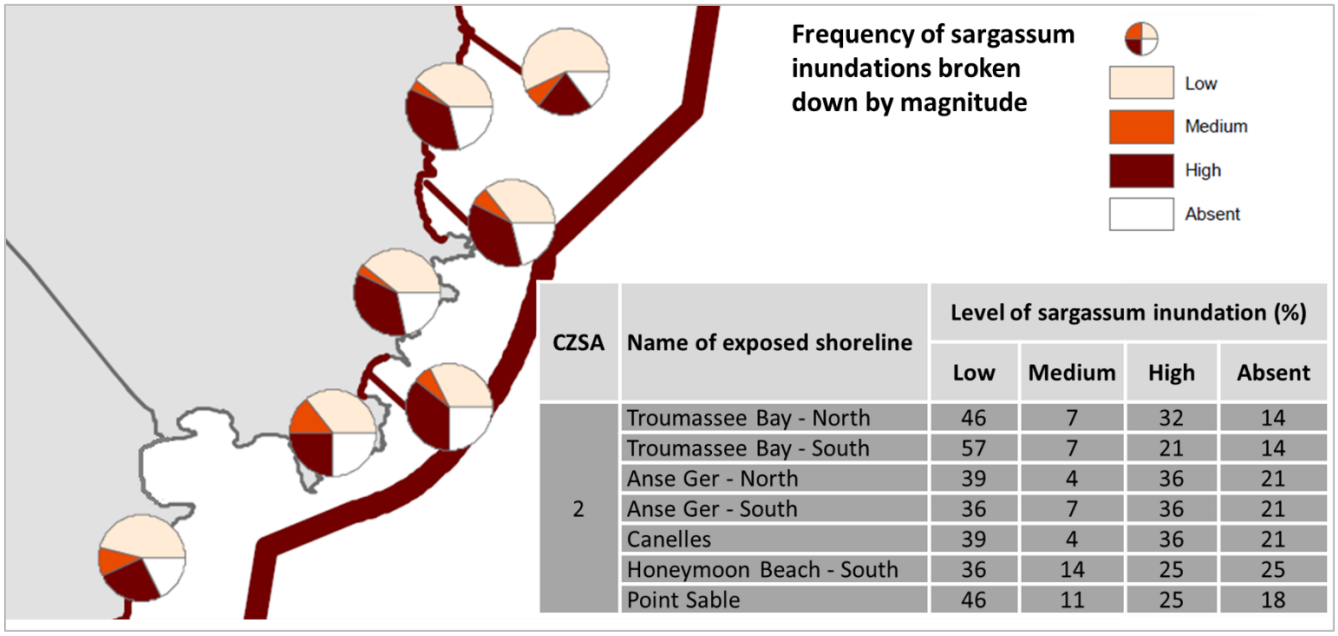
Hazard maps were created to simultaneously visualize both frequency and magnitude of the sargassum inundations at two different resolutions (i.e., at the level of the CZSAs, and at a finer resolution showing individual beach sites within CZSAs). For the CZSAs a colour scale was developed based on the overall frequency of observed inundations for the period 2011-2021. An example of the data and the colour scale used to represent frequency of the hazard by CZSAs is presented in Figure 5.



CZSA	Frequency of inundation (%)
1	89
2	70
3	90
4	81
5	8
6	0
7	8
8	40

Figure 5. Excerpt of hazard map for Barbados showing the data for frequency of inundations and the colour scale used to depict % frequency of sargassum inundations for CZSAs

For the individual beach sites/shoreline a 4-colour key was used to depict the magnitude of any observed inundations over the period 2011-2021, and the frequency of inundations at each level of magnitude over this time period was represented as a pie chart. An example of the data, the 4-colour key for magnitude and the site-specific pie charts is presented in Figure 6.



CZSA	Name of exposed shoreline	Level of sargassum inundation (%)			
		Low	Medium	High	Absent
2	Troumassee Bay - North	46	7	32	14
	Troumassee Bay - South	57	7	21	14
	Anse Ger - North	39	4	36	21
	Anse Ger - South	36	7	36	21
	Canelles	39	4	36	21
	Honeymoon Beach - South	36	14	25	25
	Point Sable	46	11	25	18

Figure 6. Excerpt of hazard map for St. Lucia showing the data and pie charts used to depict sargassum hazard at individual sites

The variation in hazard frequency and magnitude among individual beach sites was also visualised graphically using stacked bar charts. Examples are shown in Figure 7.

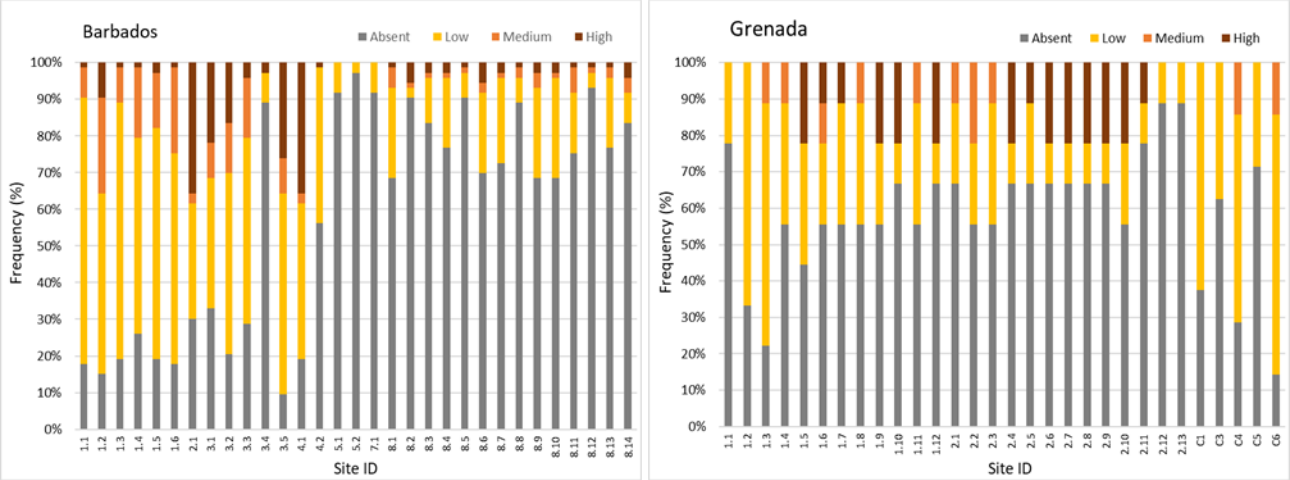


Figure 7. Examples of stacked bar charts showing sargassum inundation hazard (frequency and magnitude) for individual beach sites in Barbados and Grenada

3.2. Exposure Maps

A series of exposure maps were created that overlaid sargassum inundation hazard on different mapped assets for tourism, fisheries and coastal ecosystems. Examples of sargassum inundation exposure maps for each asset category are shown in Figure 8.

3.3. Emergence of Spatial Patterns

Certain patterns emerged from mapping and graphing of sargassum inundations as a hazard and the exposure of key assets, as described here.

Results confirm that windward and adjacent coastlines (eastern, northeast and southeast) receive the most frequent and higher magnitude inundations, with no observations of inundations on the most sheltered (western) coastlines. Note that we are aware from personal experience in Barbados that inundations do occasionally occur on the west coast, but none were observed in the sample of images studied, confirming again that such occurrences are indeed very unusual and generally associated with temporary, uncharacteristic reversal of the dominant NE Tradewinds.

Results suggest that project countries, all within the Eastern Caribbean Lesser Antilles island arc, vary with regard to the frequency and magnitude of sargassum inundations experienced over the last decade. For example, beach sites in St. Lucia appear to be subject to a greater frequency of high magnitude inundations than the other four project countries, while sites in Dominica appear to have a relatively low frequency of inundation overall. A contributing factor to this observation is related to where beach sites are located around the island – beach sites on the most windward facing coastline are more likely to receive high magnitude inundations, so countries with more beaches along this coastline will experience greater sargassum hazard. However, alternative or additional explanations for these patterns are also likely to be related to variation in the hydrographic conditions of project countries, based on their location

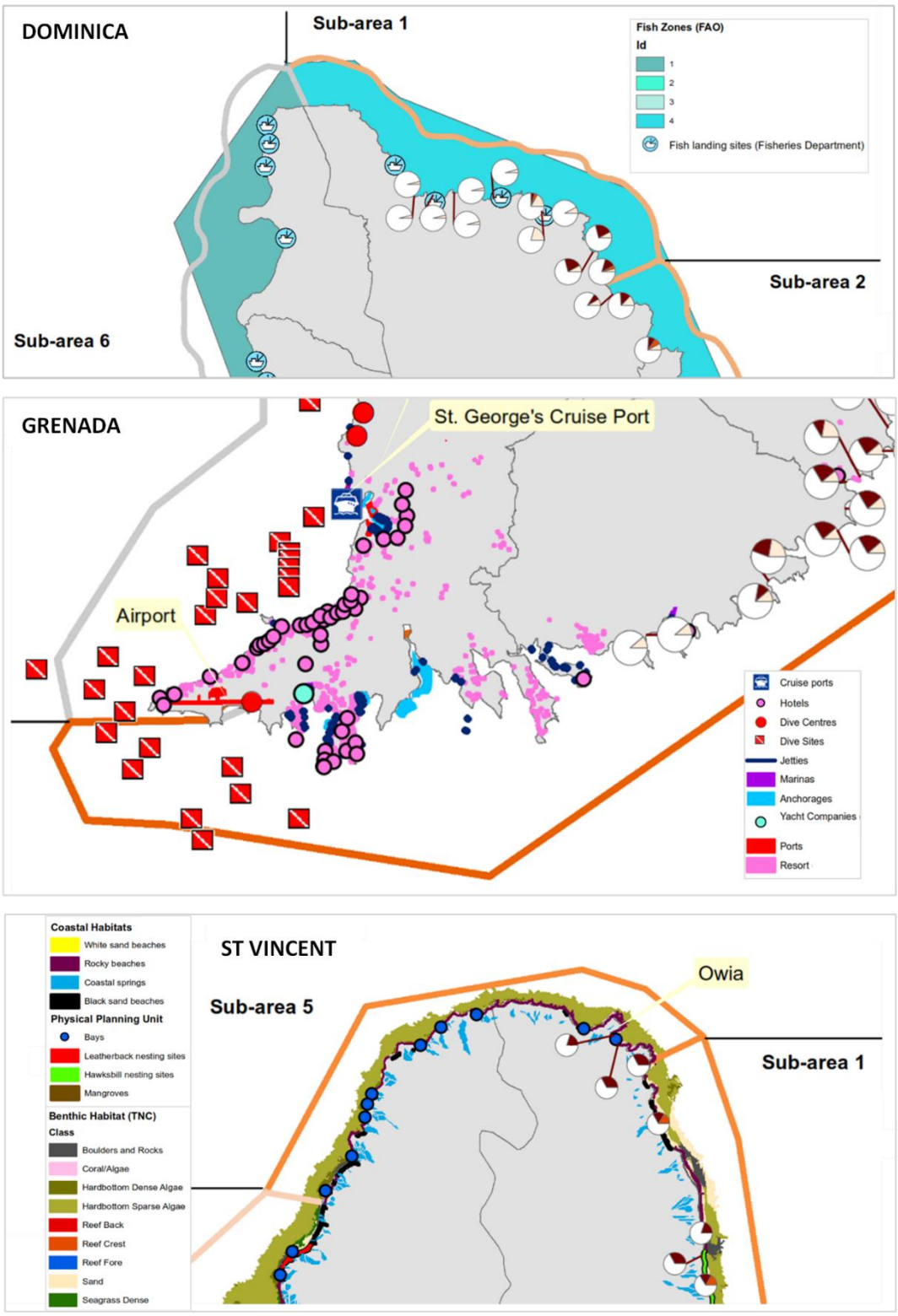


Figure 8. Excerpts from sargassum inundation exposure maps for fisheries assets (Dominica), tourism assets (Grenada) and coastal ecosystems assets (St Vincent)

And seafloor topography. For example, the forecasting of sargassum influxes for the Eastern Caribbean islands (Sargassum Sub—regional Outlook Bulletin)[1] is done separately for southern (including Grenada), middle (Barbados, St. Vincent and the Grenadines and St. Lucia) and northern (including Dominica) islands in the Lesser Antilles chain, to better reflect the different ocean current fields affecting these islands and determining sargassum influx patterns (Johnson and Franks 2019). In addition, the low sample size of observations, especially for Grenada and St. Vincent and the Grenadines, distorts the frequency observations.

The specific sites identified as subject to frequent high magnitude inundations are consistent with sites highlighted in informal observations as being the worst affected, and corroborate anecdotal observations reported in the draft Sargassum Adaptive Management Strategies (SAMS) developed for most of the study area islands under the FAO-CC4FISH project.

Tourism exposure tends to be on south and southeast coastlines, since west coasts (where tourism is often concentrated) tend to be minimally exposed. The spatial distribution of exposure to ecosystems varies considerably across the islands, since each has a different distribution of the ecosystems themselves. Fisheries exposure is quite variable among the countries, with fisheries infrastructure generally concentrated on westward coastlines, although there are important fisheries assets on the east coast of some islands such as Dominica. Exposure mapping and analysis would benefit from more accurate and more comprehensive spatial data on assets. For example, data on fishing grounds and tourism attraction sites is lacking.

3.4. Challenges and Limitations

The development of hazard and exposure maps for sargassum inundations in this study was subject to several challenges and limitations. Firstly, there are challenges inherent in measuring and evaluating sargassum inundations as a hazard.

Currently, there is no standard means of measuring or evaluating the magnitude or intensity of sargassum inundations, or their spatial extents, whereas, for example, there is a standard scale for quantifying hurricane magnitude (the Saffir-Simpson Hurricane Wind Scale). Possible parameters for measuring magnitude could include the surface area and thickness of beached sargassum, but these parameters may be difficult to measure for sargassum that accumulates in the nearshore water column. Therefore, for the purposes of this study, we developed a simple, qualitative scale for magnitude of influx that may lend itself to further use because of ease of application.

Similarly, there is currently no standard definition of the sargassum inundation hazard in terms of frequency or duration of events. It is indeed challenging to define a single inundation event. The influx delivering the sargassum to the shore may continue to deliver additional volume once the initial inundation has begun. Once stranded, the sargassum itself and the plume of discoloured, poor quality water that results from its decay can linger for an extended period of time, beyond the cessation of delivery of new sargassum to the shoreline. One option may be to estimate the number of days per year that a site typically experiences inundation effects. The frequency calculated in this research approximates such a metric, but there are limitations in the sample of observations as outlined below.

[1] https://www.cavehill.uwi.edu/cermes/projects/sargassum/outlook-bulletin.aspx

In general, the maps are of low or coarse resolution, but broad in coverage (island-wide). The smallest spatial unit in the assessment, the individual beach or bay, is not uniform in size or length. These spatial units are also not necessarily contiguous, since cliff shoreline areas were not assessed in this study. Where the overall frequency is shown on the maps at the level of the CZSA, there is an inherent averaging effect that will mask details at the scale of the individual beach site.

This assessment does not consider, and the mapping therefore does not show, the onshore-offshore extents of sargassum inundations. We have been able to extract an indication of how often low, medium or high quantities of sargassum are visible on beaches in remotely sensed images, but this does not indicate the offshore extent of the inundation. The exposure mapping shows whether assets are in proximity to sites experiencing frequent inundations and of what magnitude. However, for example, while beaches in a certain area may have been shown to receive high magnitude influxes with high frequency, this does not tell us where coral reefs offshore are impacted by sargassum accumulating or by the decay plume. More detailed assessment of site dynamics in relation to the inundation would be required to make conclusions about whether the sargassum inundations reach specific assets.

Observation of sargassum inundations is not a goal of the secondary source of remotely sensed images (Google Earth), and there are a number of limitations inherent in using this source as indirect 'observations' of sargassum inundations:

- Many images provided only partial coverage of a given island, and in some cases, cloud cover obscured the areas of interest. We sought to partially mitigate this limitation by developing a process to make inferences about unobserved or obscured sites from patterns observed in images with full coverage as described in the methodology.
- The sample sizes (n) (i.e., the total number of observations, including from complete images, partial images, and inferences) are in general small, and the time interval between images is not regular. Sample size also varies across the five countries, because there were more images available for some than others (Table 3). Barbados has the highest sample size, and sample sizes for Grenada and St. Vincent and the Grenadines are especially small (<10 observations over 10 years). The small sample sizes may bias the results so that they are not necessarily truly representative of the reality, including not picking up any seasonal variations.

Table 3. Sample size (number of remotely sensed images) by country

COUNTRY	**Sample Size (n)**
Barbados	73
Dominica	24
Grenada	9
St. Lucia	18
St. Vincent and the Grenadines	6

In addition, there are some limitations inherent in the use of available secondary data from a range of sources for asset mapping. The accuracy and completeness of the data sets cannot be validated with a high degree of certainty, and it is likely that there are gaps and inaccuracies.

3.5. Potential as a Planning Tool

Notwithstanding the challenges and limitations (Section 3.4), the broad (island-wide) coverage and coarse-resolution characterisation of sargassum inundations, together with exposure of key coastal assets produced by this research, provide a useful framework for systematic and strategic response planning. This exercise and its outputs demonstrate the usefulness of the approach taken and also allow us to assess how improvements can be made, and also provide a template for potential future iterations of the mapping.

Using secondary data sources as inputs to the hazard and asset mapping entailed limitations (as described), but facilitated a relatively simple, low cost, low effort study to test the application of this approach in a data poor environment and develop a template for mapping exposure to sargassum inundations.

Even at the current coarse resolution, the mapping provides a solid basis for systematic and strategic planning, and would support the following:

- If clearing sargassum is part of the response, target sites can be prioritised according to their typical inundation magnitude and frequency (hazard level) and/or the exposed assets in proximity.
- Choice of suitable locations for harvesting sargassum for valorisation.
- Design of a targeted monitoring programme to support improvement of the hazard mapping and further adaptive improvements to the response.
- Identification of specific sites or assets of concern as subjects of more detailed study incorporating more detailed exposure, vulnerability and impact assessment. For example, in Barbados, River Bay – assess the ecosystem impacts, and for the southwest coast sub-area 8 – assess tourism focused on this area, since this is the main area that impacts occur.

4. CONCLUSIONS

This research establishes the value of applying combined hazard risk assessment and spatial planning tools to the problem of episodic sargassum inundations. Despite several challenges and limitations including the broad coverage, low resolution map outputs developed with data inputs from secondary sources, the produced hazard and exposure maps are nonetheless useful as planning tools, and the approach provides a template for future iterations of exposure mapping and a counterpart to future vulnerability assessments for determining sargassum impacts.

We offer a number of recommendations as outlined below:

- Further research into developing a standard metric for assessing sargassum inundation hazard, for example, improving the magnitude rating and frequency metric developed under this study.
- Use of the hazard and exposure maps as a basis to develop monitoring programmes for sargassum inundations, incorporating lessons learned on how to measure sargassum as a hazard, for example the drone-assisted sargassum monitoring protocol currently under development under the SargAdapt project (Baldwin et al. 2022).

- Improve the accuracy of the hazard mapping by improving the input data, either by using the monitoring data (fit for purpose primary data replaces secondary data as input) or obtaining better secondary data for example acquisition of additional satellite images from commercial sources to increase sample size.
- Select sites with high levels of exposure as case studies for further study, such as vulnerability and impact assessments and potential as harvesting sites.
- Incorporation of sargassum hazard and exposure maps into other multi-hazard risk response planning initiatives and or broader national spatial planning and policy, e.g., Barbados Physical Development Plan (PDP) and Integrated Coastal Zone Management Plan. The alignment of the maps with existing frameworks (CZSAs) lends itself to integration.

Some of these are actions that countries could undertake as part of their response, with the exception of integration into national policy and planning, these actions could also be tested through research on a smaller scale to prove the concept.

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ANNEX 1

Country-Specific Sargassum Hazard and Exposure Mapping and Description

ANNEX 1 Country-Specific Sargassum Hazard and Exposure Mapping and Description

Barbados

Spatial Distribution of Hazard Frequency and Magnitude

Based on available Google Earth imagery from 2010 to 2021, beaches exposed to sargassum inundation make up 28.64 km (29.5%) of the coastline of Barbados. This was further examined for the eight CZSAs. Of these, all except sub-area 6 (west coast) have been exposed to sargassum inundations over the years (

Figure 10, Table 4). Sargassum inundations occur mainly on the southeast, east and northeast coasts, and to a lesser extent on the southwest and northwest (

Figure 10). The level of inundation varies among sub-areas, with sub-areas 1 to 4 being the most exposed and sub-area 3 (southeast coast) receiving sargassum 90% of the time (Table 4). This contrasts with sub-area 5 (northwest coast) and 7 (southwest coast) that receive sargassum just 8% of the time (

Figure 10, Table 4). Whilst sub-area 8 has the largest number of exposed beaches (10), sub-area 3 has the greatest length of exposed coastline (14.23 km) (Table 4).

At a higher spatial resolution, the frequency and magnitude of inundations vary among the 31 beaches within sub-areas. Beaches experiencing the most frequent (>15% of the time) high inundations levels include Skeete's Bay (sub-area 2), Consett Bay, Bath and Walkers (sub-area 3), and River Bay (sub-area 4) (Table 5, Figure 9). Barbados has four major coastal towns; however, Oistins is the only town exposed to sargassum.

Note that the sample size (n) for Barbados is the highest amongst the study area countries (n=73), so that hazard magnitudes and frequencies are likely the most representative of reality.

Table 4. Sargassum inundation frequency, number of exposed beaches, and length of exposed shoreline by coastal zone sub-area (CZSA) in Barbados.

CZSA	Frequency of sargassum inundation (%)	Number of exposed individual beaches/bays (spatial unit)	Total length of exposed beach (km)
1	89	6	4.73
2	70	1	0.17
3	90	5	14.23
4	81	2	0.51
5	8	2	0.16
6	0	0	0
7	8	1	2.20
8	40	14	6.64
Totals		**31**	**28.64**

*Table **5**. Frequency and magnitude of sargassum inundations for individual beach sites by coastal zone sub-area (CZSA) in Barbados. Frequency is shown as % of all available images. Highlighted boxes indicate sites with the greatest frequency (>15%) of high-magnitude exposure. Sub-area 6 is not exposed to sargassum and is therefore not represented here.*

CZSA	Name of exposed shoreline	Site ID	Frequency of sargassum inundation (%) by magnitude				Length of exposed beach site (m)
			Low	Medium	High	Absent	
1	Silver Sands	1.1	73	8	1	18	655
	Long Beach	1.2	49	26	10	15	1,657
	Foul Bay	1.3	70	10	1	19	654
	Crane/Belair	1.4	53	19	1	26	675
	Sam Lords Castle	1.5	63	15	3	19	605
	Bottom Bay	1.6	58	23	1	18	439
2	Skeete's Bay	2.1	32	3	36	30	172
3	Consett Bay	3.1	36	10	22	33	304
	Bath	3.2	49	14	16	21	3,027
	Martins Bay	3.3	51	16	4	29	592
	Tent Bay	3.4	8	0	3	89	502
	Walkers*	3.5	55	10	26	10	9,806
4	River Bay	4.1	42	3	36	19	262
	North East Point	4.2	42	0	1	56	244
5	Archers Bay	5.1	8	0	0	92	20
	Harrisons Point	5.2	3	0	0	97	142
7	Carlisle Bay	7.1	8	0	0	92	2,202
8	Hilton/Drill Hall	8.1	25	5	1	68	501
	Savannah	8.2	3	1	5	90	172
	Hastings	8.3	12	1	3	84	539
	Boardwalk	8.4	19	1	3	77	1,195
	Sandy Beach	8.5	7	1	1	90	480
	Worthing/St. Lawrence	8.6	22	3	5	70	534
	Southern Palms	8.7	23	1	3	73	482
	Salt Ash/Ocean 2	8.8	7	3	1	89	180
	Maxwell	8.9	25	4	3	68	1,184
	Welches	8.10	27	1	3	68	606
	Oistins	8.11	16	7	1	75	153
	Bus Terminal	8.12	4	1	1	93	77
	Enterprise/ Miami Beach	8.13	19	3	1	77	332
	Cotton House	8.14	8	4	4	84	211

* This continuous stretch of beach includes Morgan Lewis, Lakes, Cattlewash and Bathsheba

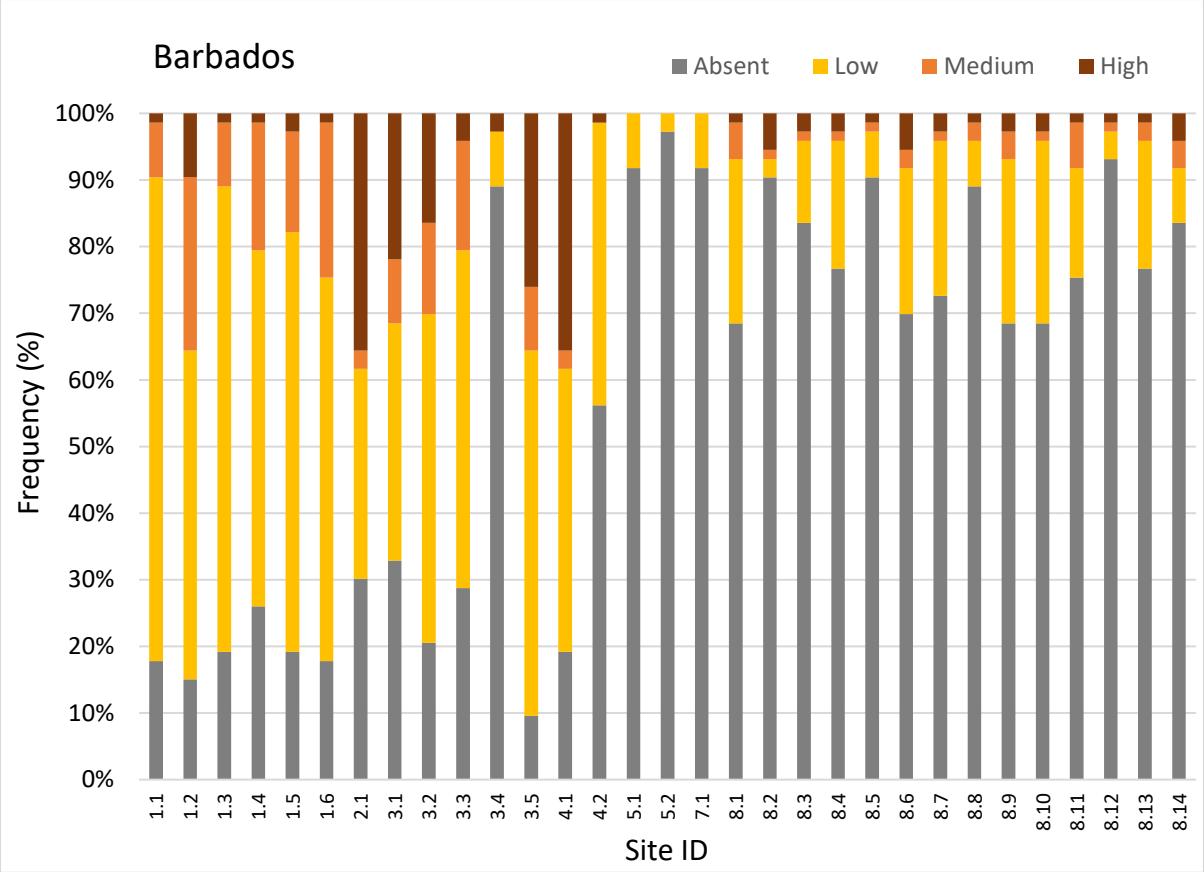

Figure 9 Frequency of sargassum inundations by magnitude in Barbados.Site names given in Table 5

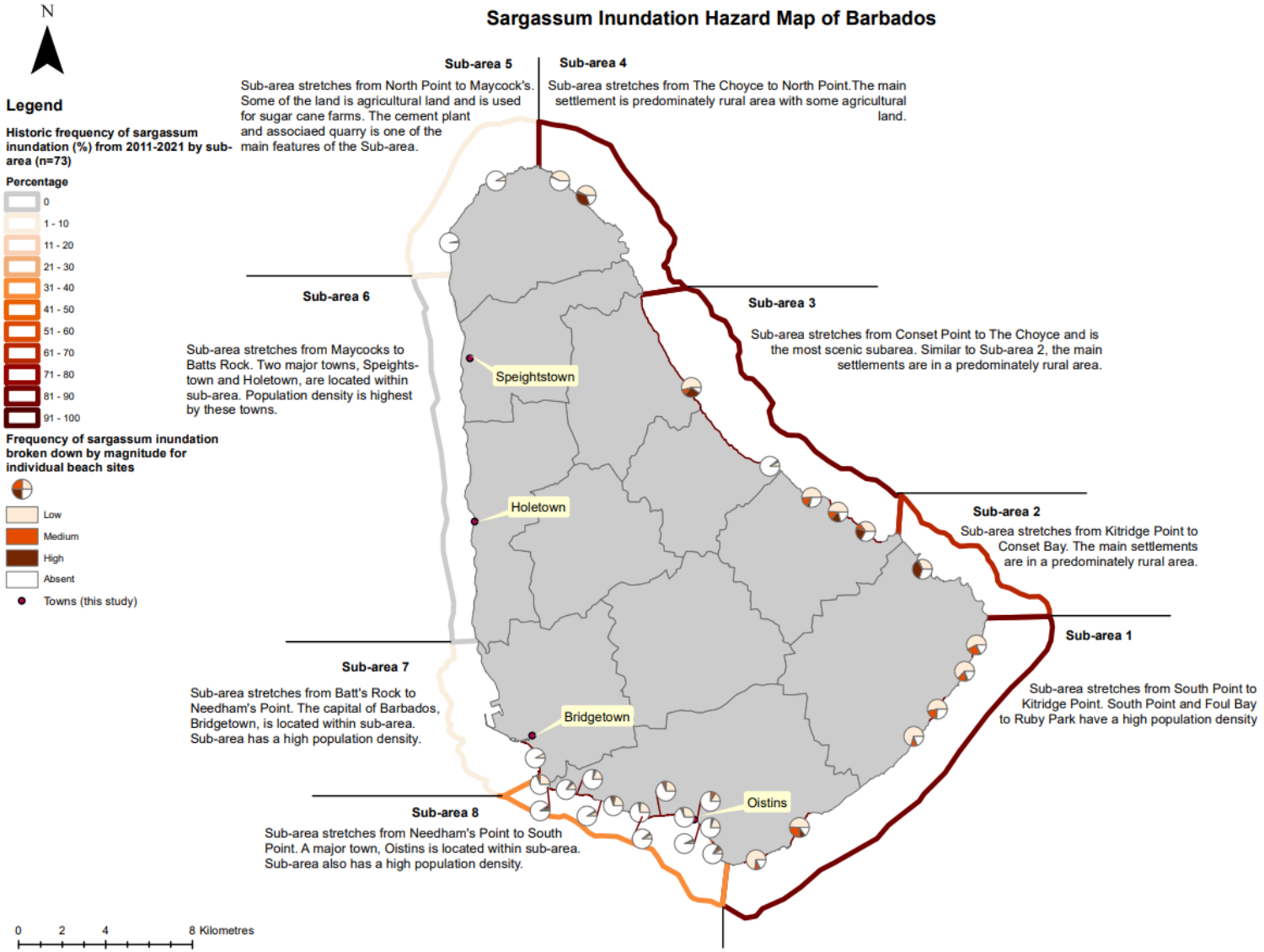

Figure 10 Map of Barbados showing the level of sargassum inundations by the eight coastal sub-areas and at 31 exposed beaches

Ecosystem exposure

Ecosystems assets for Barbados are represented by a pre-existing marine benthic habitat map layer showing 11 habitat categories (algae hard ground, coral rubble, gorgonian patch reef, hard coral framework reef, hard coral patch reef, mixed reef hard ground -fathom type, mixed reef hard ground – north pavement, reef crest, reef flat, sand, and spur and groove), to which seagrass areas, marine designated areas and point locations of bird swamps, sea turtle nesting sites and wetlands have been added (Figure 2).

The most commonly exposed ecosystem is that of sandy beaches which occur around most of the island. Among the many ecosystem services of beaches is provision of suitable nesting sites for endangered sea turtles. Fortunately, most of the nesting sites (at least for hawksbill turtles) are located on the leeward side of the island which has no (west coast) or a relatively low level (southwest coast) of exposure to sargassum (Figure 11). However, green and leatherback turtle nesting sites which are mainly located on the southeast and east coasts of the island are exposed to sargassum. Migratory shorebirds also rely on beaches and coastal wetlands (including 'bird swamps', brackish ponds and mangroves) for forage and shelter, and some resident species also forage, roost and nest in these areas.

Several wetlands, located on the windward side of the island (east and southeast coasts) are exposed to sargassum inundations. Three in particular, River Bay, Green Pond and Long Pond, are located in areas that are highly exposed to sargassum, with frequent heavy inundations. It is worth noting, however, that the largest mangrove swamp, located at Graeme Hall on the southwest coast is landlocked and therefore not directly exposed to sargassum. Likewise, the several small areas of fringe mangroves are mostly located along the west coast which is not exposed to sargassum.

Hard coral reefs and associated soft coral habitats are located around the north, northeast, southeast, southwest and west coasts, and are largely absent along most of the east coast where sargassum inundation is frequent and of high magnitude (Figure 11). Furthermore, the shallowest nearshore hard coral reefs (fringing reefs) are only found on the west coast which is not exposed to sargassum. Hard coral framework reefs and patch reefs along the coastal areas exposed to sargassum are generally a little further offshore and deeper than the fringing reefs but would still be exposed to the sargassum brown tide (plume of brown poor quality water released by decaying wet sargassum trapped along shorelines).

Seagrass is scarce in Barbados but occurs in a few low-density meadows in small pockets along the east coast (Consett Bay, Bath) which are highly exposed to sargassum. Sparse seagrasses also occur in patches along the southwest coast (Worthing/St Lawrence) and Carlisle Bay which have mostly relatively low levels of sargassum exposure (Figure 9, Table 5). However, existing available information on seagrass extent may be out of date.

The island has two marine designated areas, Folkestone Marine Reserve located on the west coast and therefore not exposed to sargassum, and Carlisle Bay Marine Park located on the southwest coast (Carlisle Bay, Hilton/Drill Hall, Savannah, Hastings), with mostly relatively low exposure to sargassum (Figure 11, Figure 9).

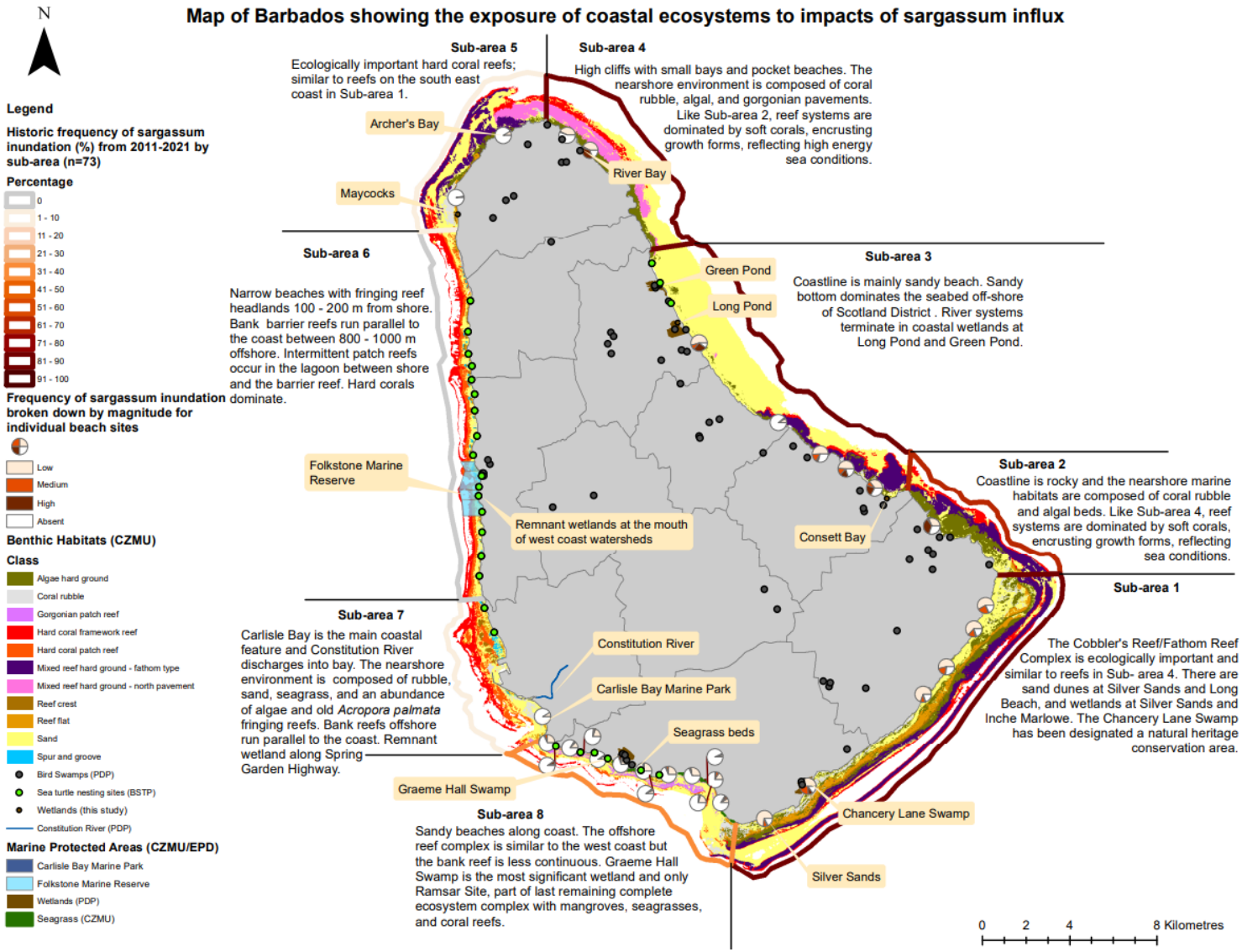

Figure 11 Map of Barbados showing the exposure of coastal ecosystems to sargassum inundations

Tourism exposure

The majority of Barbados' tourism assets are located on the west and southwest coast (sub-areas 6, 7 and 8), along the coast of the island's densely developed urban corridor. Those on the central west coast (sub-area 6) are not directly exposed to sargassum, whilst those along the south end of the west coast and Carlisle Bay area (sub-area 7) have generally low exposure (low frequency and low magnitude inundations) (Figure 12). Most of the southwest coast (sub-area 8) however, has a higher level of exposure to sargassum with sargassum inundations occurring 40% of the time and at a medium level of magnitude (Figure 9, Table 5). These southwest coast tourism assets include hotels, restaurants, coastal beach parks, water sports areas, dive sites and surf spots, especially in high density tourist areas such as Carlisle Bay, St. Lawrence Gap and Oistins.

There are also tourism assets on the southeast coast (sub-area 1), albeit lower density. These include hotels, notably The Crane Resort, a few popular surf, windsurf and kiting spots, and coastal beach parks (Silver Sands, Long Beach). This sub-area generally has much higher sargassum exposure (81% frequency of inundations overall, with medium to high levels of magnitude occurring between 10 and 35% of the time) (Figure 9, Figure 12, Table 5). Though not mapped as such, there are also tourism assets located on the more exposed east, northeast and south-east coast in the form of attraction sites, mainly specific beaches that attraction visitation for their rugged visual amenity or certain types of water sports.

Designated ship and yacht anchorages and seaports on the island are located on the west coast (no sargassum exposure) and Carlisle Bay with low exposure.

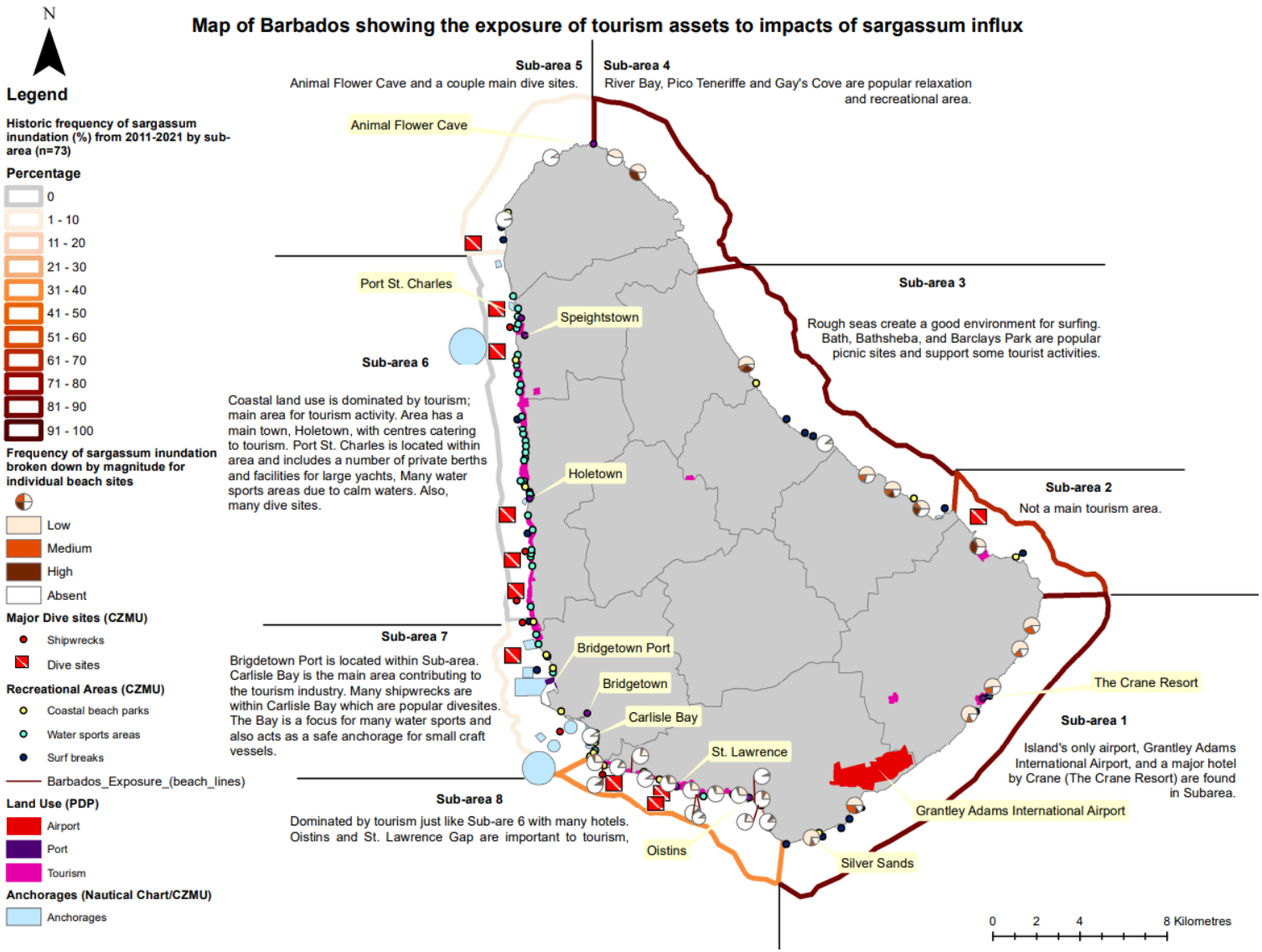

Figure 12 Map of Barbados showing the exposure of tourism to sargassum inundation

Fisheries

Barbados has 31 officially designated fish landing sites, most of which also have adjacent vessel mooring areas nearshore and/or beach haul-up areas. Most of these are located on the west and southwest coasts with relatively low frequency of sargassum inundation. However, there are 9 landing sites on the southeast and east coasts that are subject to higher frequency inundations (Figure 13, Table 6).

Skeete's Bay and Consett Bay (sub-areas 2 and 3 respectively) in particular have significant fishery infrastructure including market facilities, jetties, moorings and haul-out areas which are subject to a high frequency of high magnitude inundations (Figure 9, Table 5). These highly exposed fish landing sites tend to focus on shallow reef fisheries including lobster and sea urchins, and nearshore small pelagic species. Fish yields from the nearshore areas adjacent to these landing sites vary from relatively low to medium, with the exception of Skeete's Bay which has relatively high fish yields (Figure 13).

Of the less exposed southwest sites, Oistins is the largest landing site with market, freezer and haulout facilities as well as moorings and a jetty. It is a major hub for the offshore pelagic fishery, but also has a relatively high fish yield from the adjacent nearshore area (Figure 13).

The fish landing sites in sub-area 7 are subject to the lowest frequency of inundations in general, with no medium or high magnitude inundations observed. Sites adjacent to the main Bridgetown Port (Pile Bay, Sandpit and Bridgetown Fisheries Complex) were not observed to experience any inundations. The Bridgetown Fisheries Complex is the largest fishery facility and main fisheries hub on the island with a harbour, cold storage, market and haul-out facilities. Informal observations suggest that arrival of sargassum within the protected harbour is rare and was not captured in the observations (reviewed images) in this study. The two landing areas in Carlisle Bay (Bay Street and Burkes Beach) are very minor and only occasionally exposed to sargassum.

Table 6. Number of fish landing sites by coastal zone sub-area (CZSA) in Barbados and the names of fish landing sites exposed to sargassum inundations.

CZSA	Number of fish landing sites	Names of sites exposed
1	4	Silver Sands
		Foul Bay
		Crane
		Long Bay
2	1	Skeete's Bay
3	4	Consett Bay
		Bath
		Martins Bay
		Tent Bay
4	0	-
5	2	Stroud Bay
		Half Moon Fort
6	11	-
7	5	Pile Bay
		Shallow Draught
		Bridgetown Fisheries Complex
		Bay Street
		Burkes Beach
8	4	Worthing
		St. Lawrence
		Dover
		Oistins

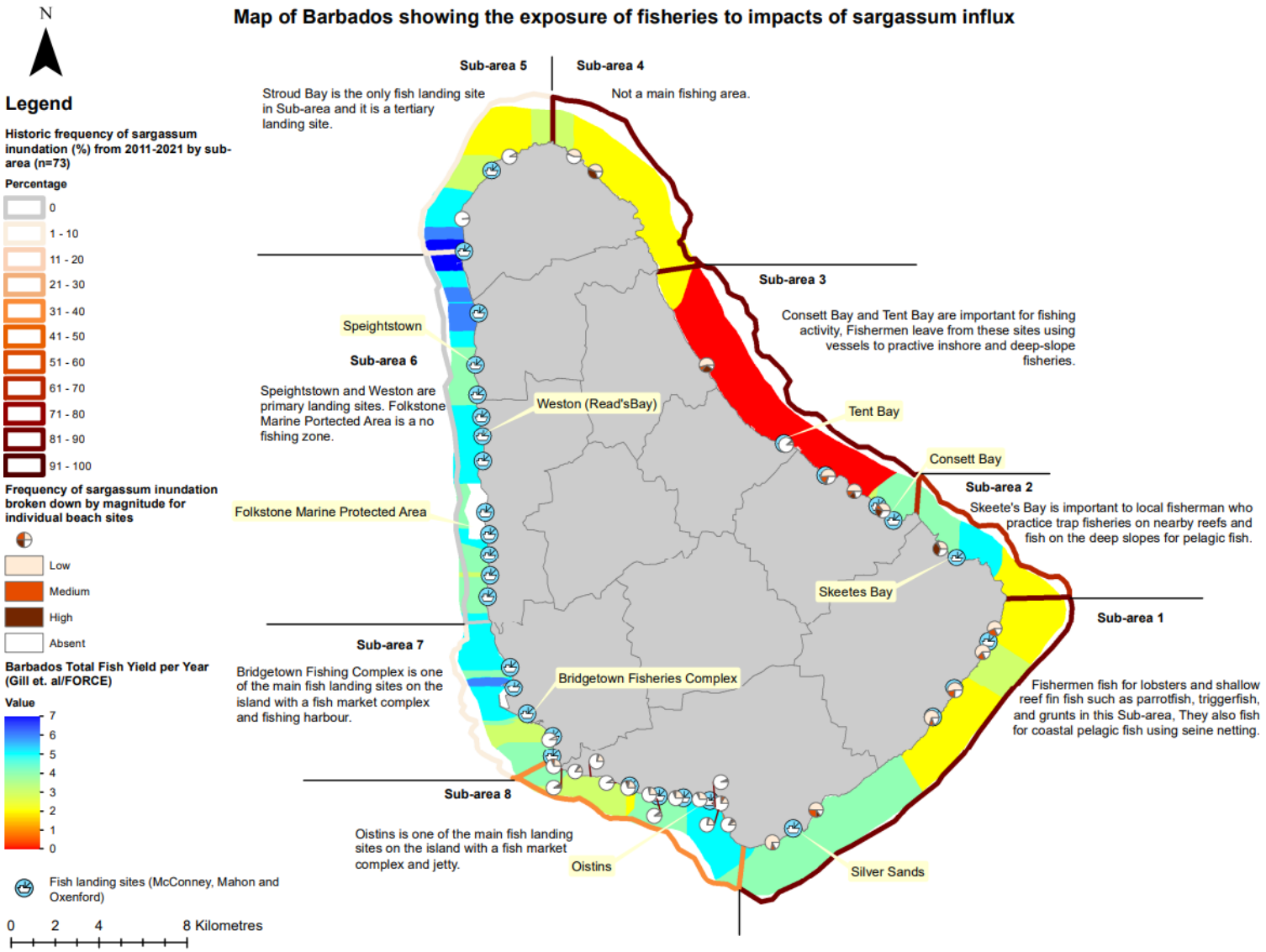

Figure 13 Map of Barbados showing the exposure of fisheries assets to sargassum inundations

St. Lucia

Spatial Distribution of Hazard Frequency and Magnitude

Based on available Google Earth imagery from 2010 to 2021, beaches exposed to sargassum inundation make up 19 km (12%) of the coastline of St. Lucia. This was further examined for the four CZSAs. Of these, all except sub-area 3 have been exposed to sargassum inundations over the years (Figure 15, Table 7). Sargassum inundations occur mainly on the southeast, east and northeast coasts, and to a lesser extent on the northwest (Figure 15). All exposed sub-areas receive sargassum 86% of the time (Table 7). Sub-area 1 and 2 both have the largest number of exposed beaches (13 each); however, sub-area 2 has the greatest length of exposed coastline (9.96 km) (Table 7). At a higher spatial resolution, frequency and magnitude of inundations are very similar among the 32 beaches within sub-areas except for the two on the leeward coast. Most beaches experience frequency of high magnitude inundation (>25% of the time); however, Esperance Bay, Labourne Bay and Plantation Beach experience the most frequent high magnitude inundations (>38% of the time) (

Table **8**, Figure 14). St. Lucia has 10 major coastal towns; however, Duaphin, Dennery, Parslin and Micoud are the only towns exposed to sargassum.

Table 7. Sargassum inundation frequency, number of exposed beaches, and length of exposed shoreline per coastal zone sub-area (CZSA) in St. Lucia. Frequency is shown as % of all available images.

CZSA	Presence of sargassum (%)	Number of exposed beaches	Length of exposed beach (km)
1	86	13	6.15
2	86	13	9.96
3	0	0	0
4	86	6	3
Total		**32**	**9.11**

*Table **8**. Frequency and magnitude of sargassum inundations for individual beach sites by coastal zone sub-area (CZSA) in St. Lucia. Frequency is shown as % of all available images.* Highlighted boxes indicate sites with the greatest frequency (>38%) of high-magnitude exposure. Sub-area 3 is not exposed to sargassum and is therefore not represented here.

CZSA	Name of exposed shoreline	Site ID	Level of sargassum inundation (%)				Length of exposed shoreline (m)
			Low	Medium	High	Absent	
1	Epouge Bay South	1.1	50	7	29	14	523
	Rogue Point	1.2	39	11	29	21	145
	Lapis	1.3	43	4	32	21	538
	Esperance Bay	1.4	36	7	39	18	122
	Esperance Harbour	1.5	0	0	14	86	390
	Esperance South	1.6	36	0	32	32	60
	Labourne Bay	1.7	29	11	39	21	170
	Marquis Bay	1.8	36	7	36	21	239
	Petit Anse	1.9	39	4	36	21	266
	Grand Anse	1.10	43	11	32	14	1,482
	Chaloupe Bay	1.11	43	4	36	18	623
	Dennery Bay	1.12	46	4	36	14	607
	Fond D Or Bay	1.13	46	4	36	14	982
2	Praslin Bay	2.1	43	4	36	18	513

	Fond Bay	2.2	39	4	36	21	637
	Micoud	2.3	43	4	36	18	234
	Troumassee Bay - North	2.4	46	7	32	14	59
	Troumassee Bay - South	2.5	57	7	21	14	1,284
	Anse Ger - North	2.6	39	4	36	21	273
	Anse Ger - South	2.7	36	7	36	21	1,096
	Canelles	2.8	39	4	36	21	274
	Honeymoon Beach - North	2.9	32	7	36	25	600
	Honeymoon Beach - South	2.10	36	14	25	25	402
	Point Sable	2.11	46	11	25	18	1,223
	Eau Piquant	2.12	46	11	25	18	1,584
	Anse Des Sables Beach	2.13	57	4	25	14	1,787
4	Vigie Beach - West	4.1	4	0	0	96	1,605
	Saline Point	4.2	4	0	0	96	214
	North Point	4.3	32	14	21	32	72
	Donkey Bay	4.4	36	18	18	29	138
	Plantation Beach	4.5	39	7	39	14	740
	Epouge Bay North	4.6	46	7	29	18	231

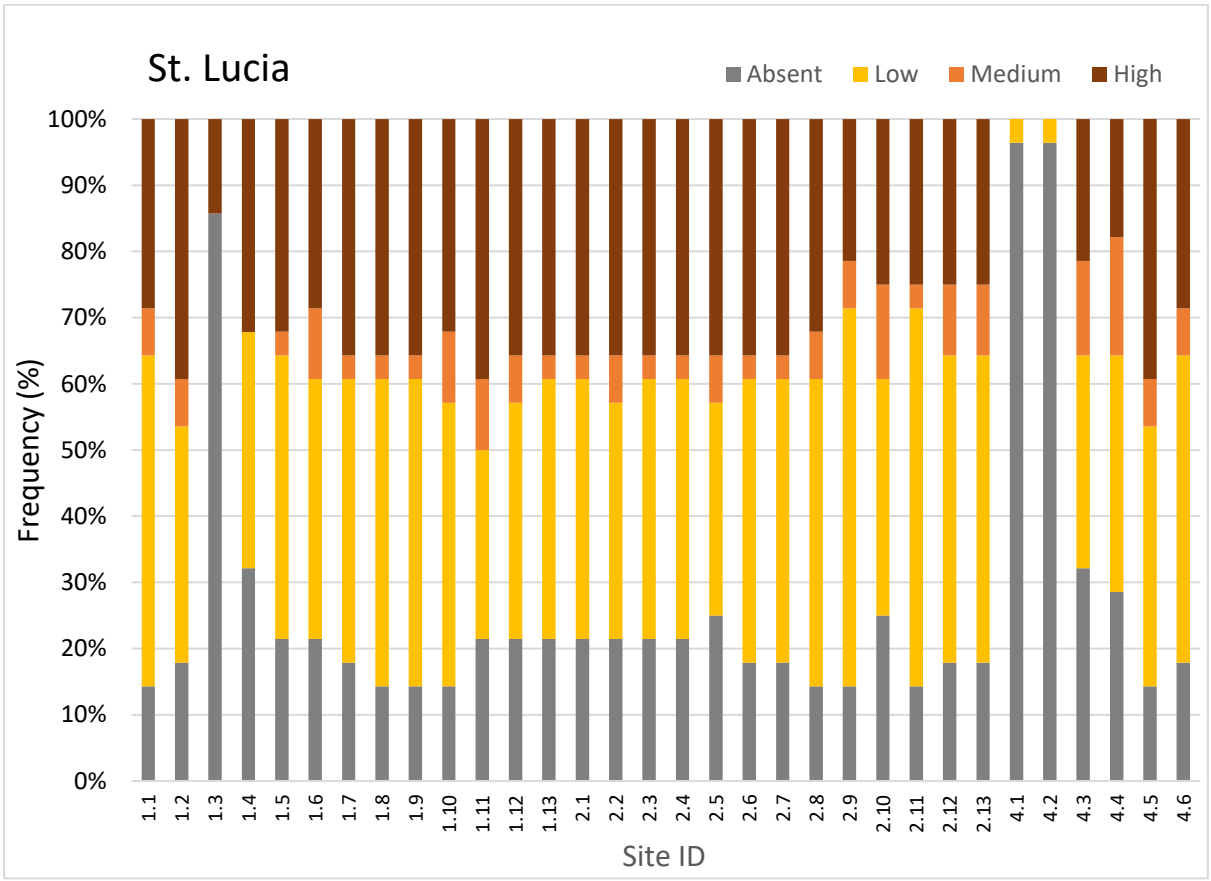

Figure 14 Frequency of sargassum inundations by magnitude in St. Lucia. Site names given in Table 8

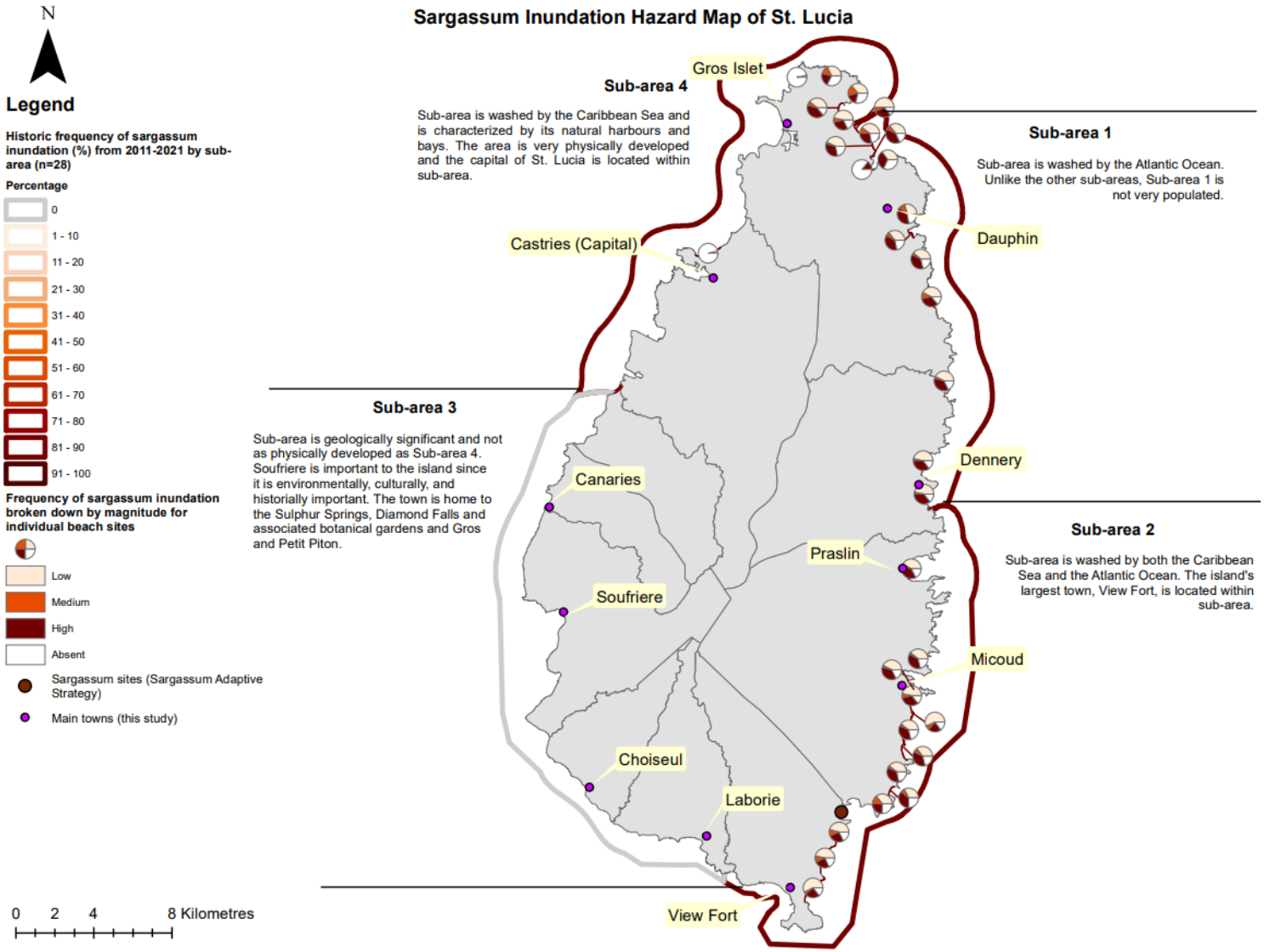

Figure 15 Map of St. Lucia showing the level of sargassum inundations by the four coastal sub-areas and at 32 exposed beaches

Ecosystem exposure

Ecosystems assets for St. Lucia are represented by a pre-existing marine benthic habitats layer showing 10 categories (boulders and rocks, coral/algae, dredged, hardbottom dense algae, hardbottom sparse algae, reef back, reef crest, reef fore, sand, and seagrass dense), rivers, sea turtle nesting sites, and wetlands and mangroves.

The most commonly exposed ecosystem is that of sandy beaches which occur around most of the island, especially in sub-area 1 which has wide sandy beaches. Among the many ecosystem services of beaches is provision of suitable nesting sites for endangered sea turtles; sub-area 1 in particular has been recognised as an important area for nesting sea turtles. The island has a small number of sea turtle nesting sites and only a few of them are exposed to sargassum. Unfortunately, they are exposed to relatively high levels of sargassum inundation (Figure 16). Several wetlands and mangroves, located on the windward side of the island (north to south coasts) are highly exposed to high levels of sargassum inundations. Two in particular, Mankote and Savannes Bay, are RAMSAR sites. A few wetlands and mangroves on the northwest coast are exposed to low levels of sargassum inundations. These mangroves are important for birds which use them as habitats as well as for fishes and lobsters which use them as nurseries. St. Lucia also has several rivers that flow into wetlands and mangroves and on the windward side of the island, many river mouths are exposed to relatively high levels of sargassum inundation.

There are sparse amounts of hard coral reefs located on the north and east to south coasts. The largest reef complex is located on the west coast which is not exposed to sargassum. Nearshore hard coral reefs along the coastal areas exposed to sargassum would be exposed by high levels of sargassum inundations and offshore hard coral reefs may be exposed to the sargassum brown tide (plume of brown poor-quality water released by decaying wet sargassum trapped along shorelines).

Seagrass is located along the leeward side of the island as well as the south, southeast and east coasts. Rich seagrass beds are found within sub-area 2 (the south, southeast and east coast) which receives frequent high magnitude inundations. Sub-area 4 also has rich seagrass beds which are located in areas that have with lesser frequency of inundation (Figure 14, Figure 16).

The island has many marine designated areas; however, only five (Savannes Bay, East Coast, Praslin, Scorpion Island, and Mankote) are located on the windward side of the island, and thereby exposed high frequency of high magnitude inundations (Figure 14, Figure 16).

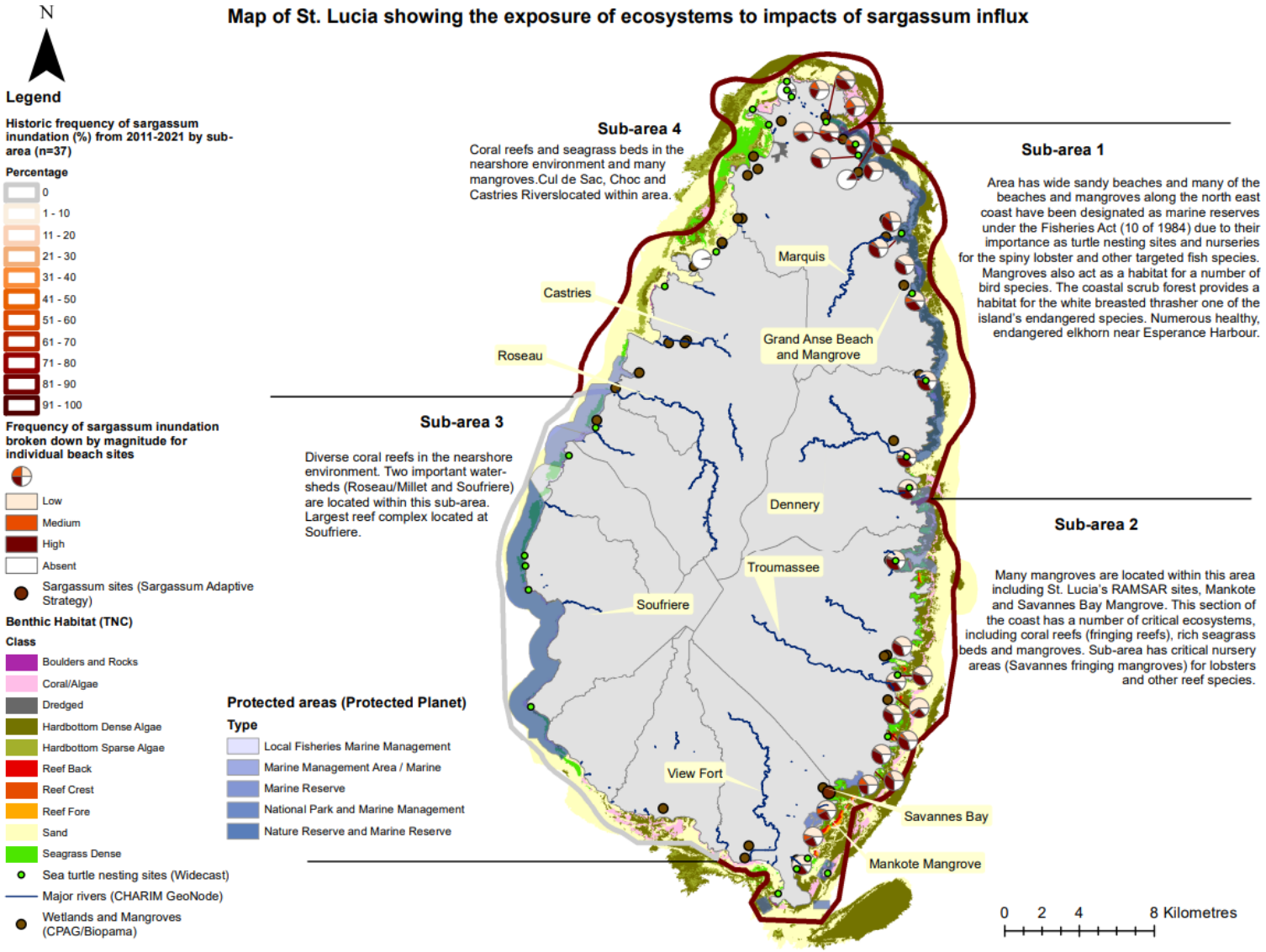

Figure 16 Map of St. Lucia showing the exposure of coastal ecosystems to sargassum inundation

Tourism exposure

In St. Lucia, there are many beach-front and nearshore tourism assets (airports, hotels and main towns) located mainly on the northwest and west coasts of the island, with a few on the south, east and northeast coasts. Those on the west coast are not directly exposed to sargassum, whilst those along the south and east coasts have generally high exposure (Figure 17). Assets around Vigie Beach on the northwest coast including George F. L. Charles International Airport, have a low exposure to sargassum inundations. Hewanarra International Airport on the south coast is, however, exposed to higher sargassum inundations.

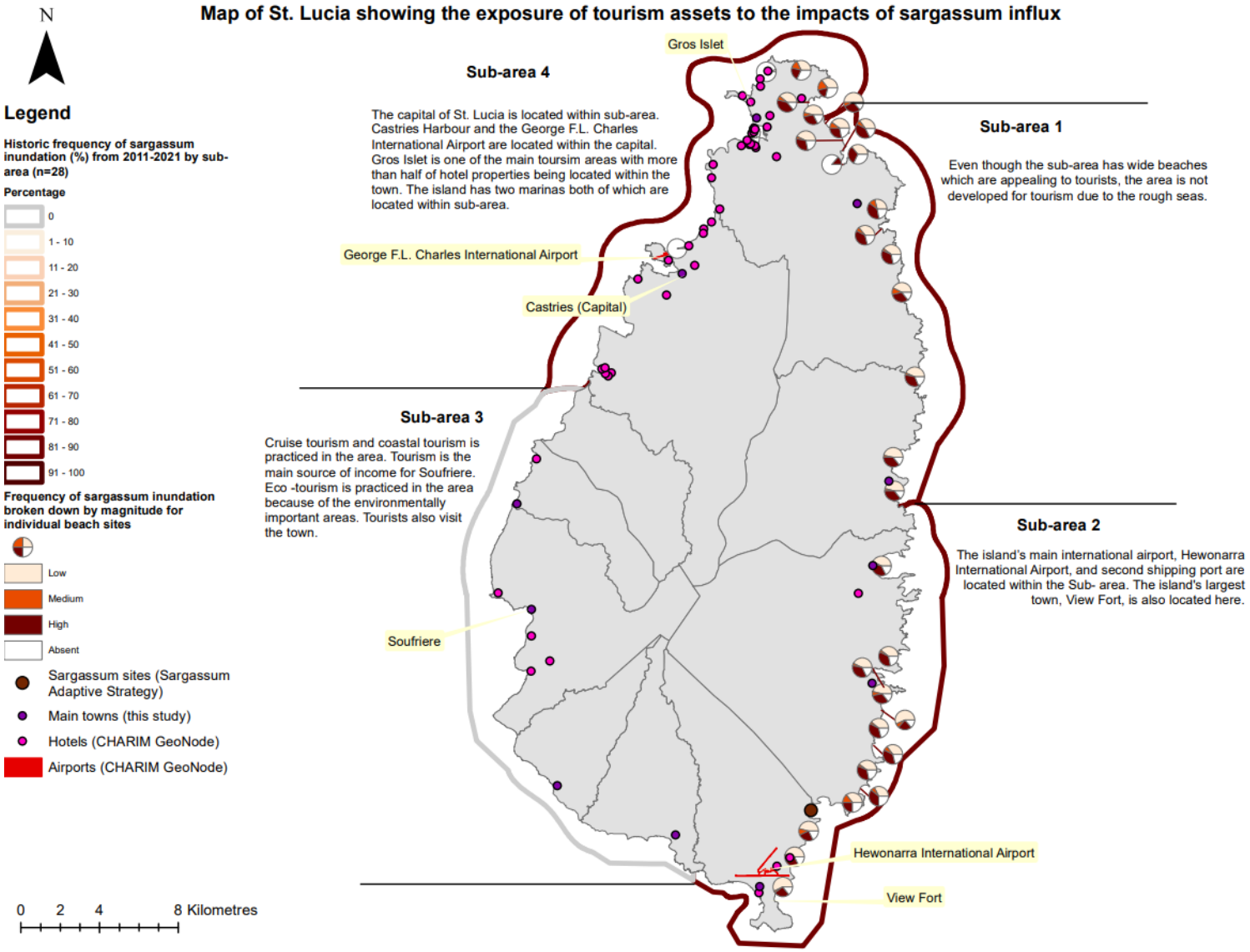

Figure 17 Map of St. Lucia showing the exposure of tourism assets to impacts of sargassum inundation

Fisheries exposure

St. Lucia has 13 officially designated fish landing sites located around the island, except on the northeast coast. Most of these are located on the leeward coast with no or relatively low exposure to sargassum. However, there are four of these landing sites on the south and southeast coasts that are exposed to high levels of sargassum and they are linked to important fishing communities which are also exposed to sargassum (Figure 18, Table 9). These highly exposed fish landing sites tend to focus on shallow reef fisheries, white sea urchin and whelk. Mangroves, seagrass beds and coral reefs found in sub-area 2 are important to the fisheries sector are also exposed to high levels of sargassum inundations.

Table 9. Number of fish landing sites by coastal zone sub-area (CZSA) in St. Lucia and the names of fish landing sites exposed to sargassum inundations

CZSA	Number of fish landing sites	Names of sites exposed
1	1	Dennery
2	4	Praslin,
		Micoud
		Savannes Bay
3	6	-
4	2	-

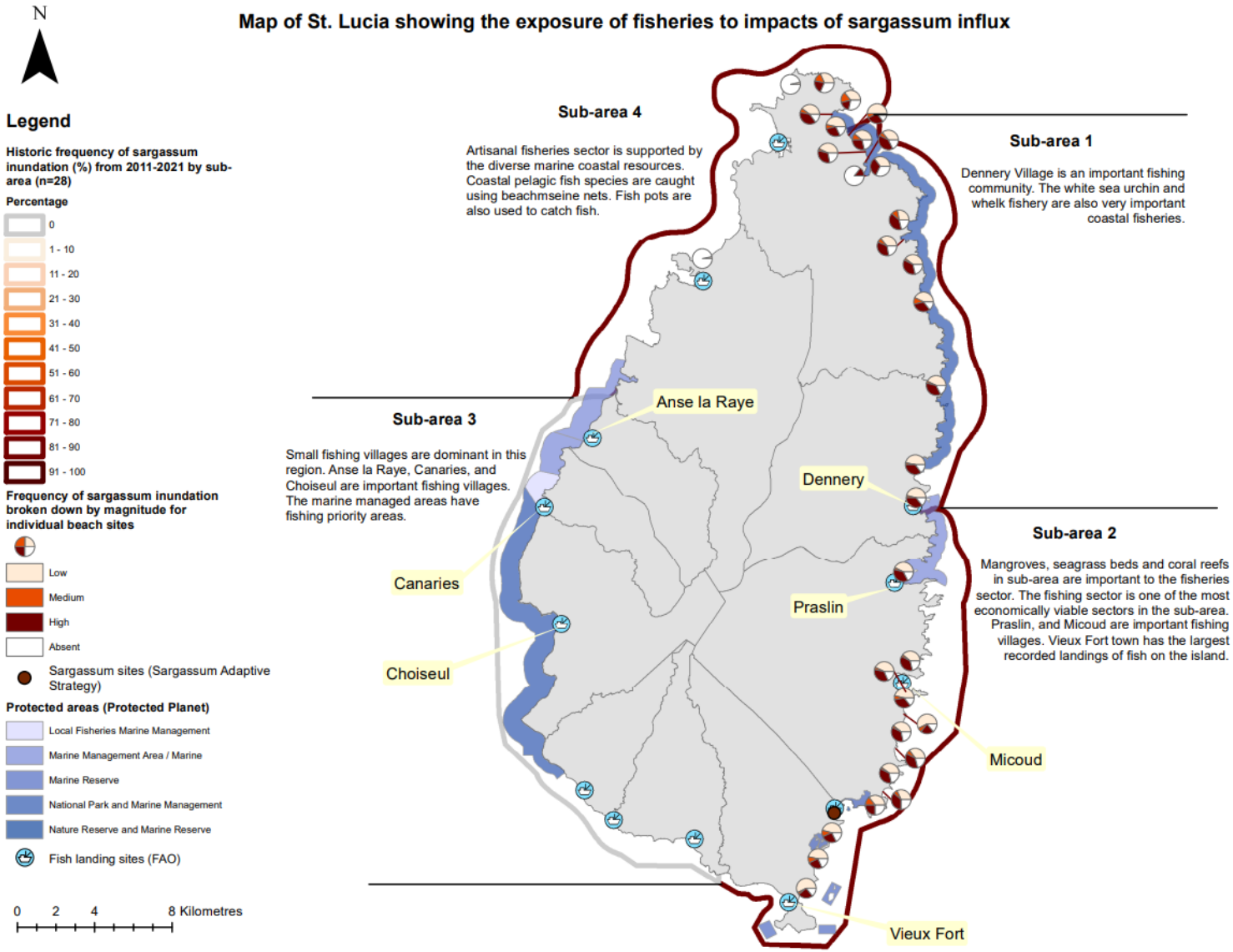

Figure 18 Map of St. Lucia showing the exposure of fisheries to impacts of sargassum inundation

Grenada

Spatial Distribution of Hazard Frequency and Magnitude

Based on available Google Earth imagery from 2010 to 2021, beaches exposed to sargassum inundation make up 15km (12%) of the coastline of Grenada. This was further examined for the four coastal sub-areas. Of these, only sub-area 1 and sub-area 2 have been exposed to sargassum inundations over the years (Figure 20, Table 10). Sargassum inundations occur mainly on the southeast, east, northeast and north coasts (Figure 20). The frequency and magnitude of inundations varies between the two sub-areas, with sub-area 1 experiencing sargassum inundation 78% of the time while sub-area 2 experiences sargassum inundation 44% of the time (Figure 20, Table 10). Similar to sub-area 1, Carriacou experiences sargassum 78% of the time (Figure 21). Even though the sub-areas have almost the same number of beaches, sub-area 1 has the greater length of exposed coastline (approx. 10 km) (Table 10). At a higher spatial resolution, the level of inundations also varies among the 25 beaches within sub-areas. Even though the beaches in sub-area 1 experience sargassum inundations more than the beaches in sub-area 2, beaches in sub-area 2 experience higher frequency and magnitude of inundation (Figure 19,

Table 11). However, exposed beaches in Carriacou mostly experience lower frequency and magnitude of sargassum inundations (Table 10).

Note that the sample size, n, for Grenada is low (n=9), so that hazard magnitudes and frequencies may be less representative of reality.

Table 10. Sargassum inundation frequency, number of exposed beaches, and length of exposed shoreline by coastal zone sub-area (CZSA) in Grenada. Frequency is shown as % of all available images.

CZSA	Presence of sargassum (%)	Number of exposed beaches	Length of exposed beach (km)
1	78	12	10.73
2	44	13	4.48
3	0	0	-
4	0	0	-
Carriacou	88	5	3.63
Total		**30**	**18.84**

Table 11. Frequency and magnitude of sargassum inundations for individual beach sites by coastal zone sub-area (CZSA) in Grenada and Carriacou. Frequency is shown as % of all available images. Highlighted boxes indicate sites with the greatest frequency (> 20%) of high-magnitude exposure. Sub-areas 3 and 4 are not exposed to sargassum and therefore not represented here.

CZSA	Name of exposed shoreline	Site ID	Level of sargassum inundation (%)				Length of exposed shoreline (m)
			Low	Medium	High	Absent	
1	Sauteurs Bay	1.1	22	0	0	78	1,930
	Levera Beach	1.2	67	0	0	33	766
	Bathway Beach	1.3	67	11	0	22	1,138
	Antoine Bay	1.4	33	11	0	56	1,992
	Conference Bay	1.5	33	0	22	44	724
	Pearls	1.6	22	11	11	56	155
	Great River Bay	1.7	33	0	11	56	1,082
	Grenville Bay	1.8	33	11	0	56	91
	Soubise	1.9	22	0	22	56	1,716

	St. Andrews Bay North	1.10	11	0	22	67	385
	St. Andrews Bay South	1.11	33	11	0	56	547
	Hope	1.12	11	0	22	67	204
2	Bacolet North	2.1	22	11	0	67	1,153
	Bacolet South	2.2	22	22	0	56	238
	Menere Bay North	2.3	33	11	0	56	188
	Menere Bay South	2.4	11	0	22	67	623
	Crochu Harbour North	2.5	22	0	11	67	205
	Crochu Harbour South	2.6	11	0	22	67	269
	La Tante Bay	2.7	11	0	22	67	252
	Galby Bay	2.8	11	0	22	67	128
	Requin Bay North	2.9	11	0	22	67	326
	Belle Isle	2.10	22	0	22	56	308
	St. Davids	2.11	11	0	11	78	131
	Westerhall North	2.12	11	0	0	89	393
	Westerhall South	2.13	11	0	0	89	269
Carriacou	Petite Carenage Beach	C1	63	0	0	38	1,115
	Windward 1	C3	38	0	0	63	969
	Windward 2	C4	57	14	0	29	947
	Windward 3	C5	29	0	0	71	275
	Windward 4	C6	71	14	0	14	321

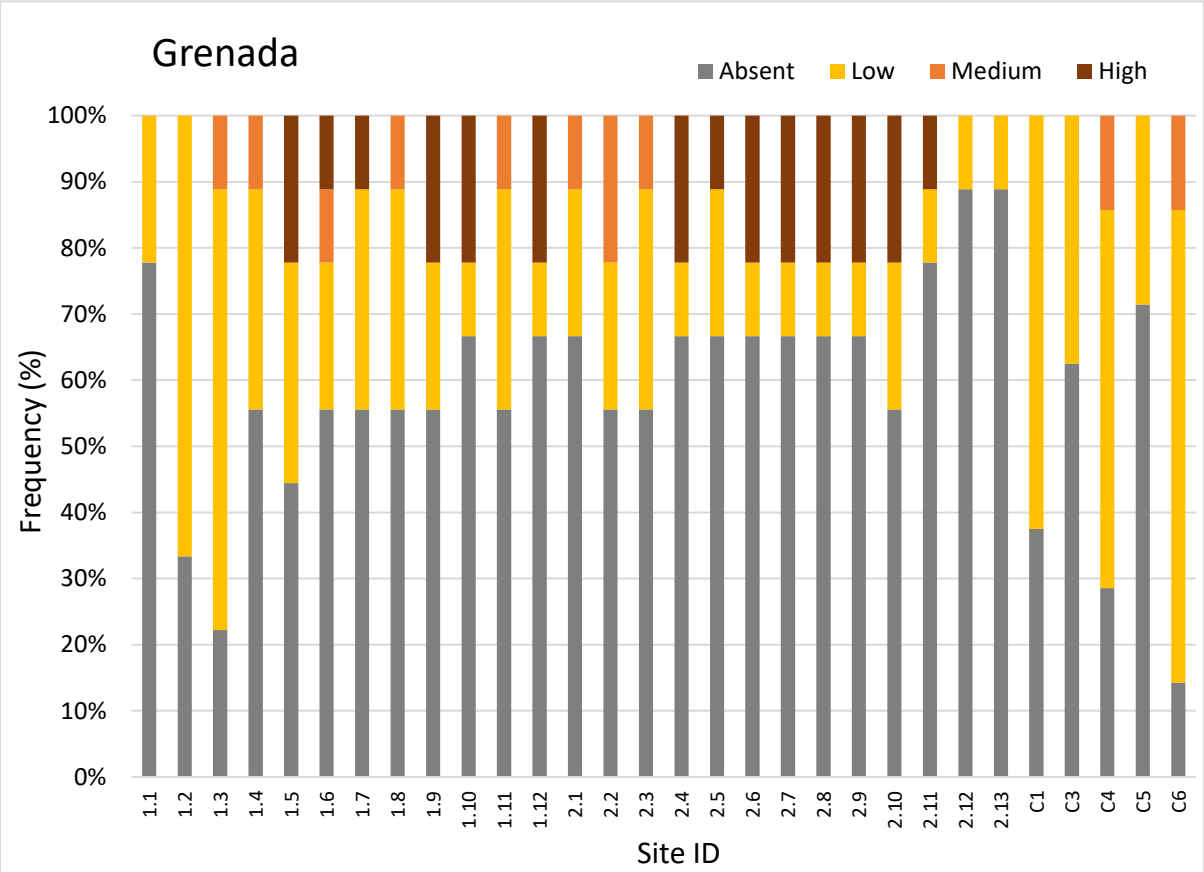

Figure 19 Frequency of sargassum inundations by magnitude in Grenada. Site names are given in Table 11

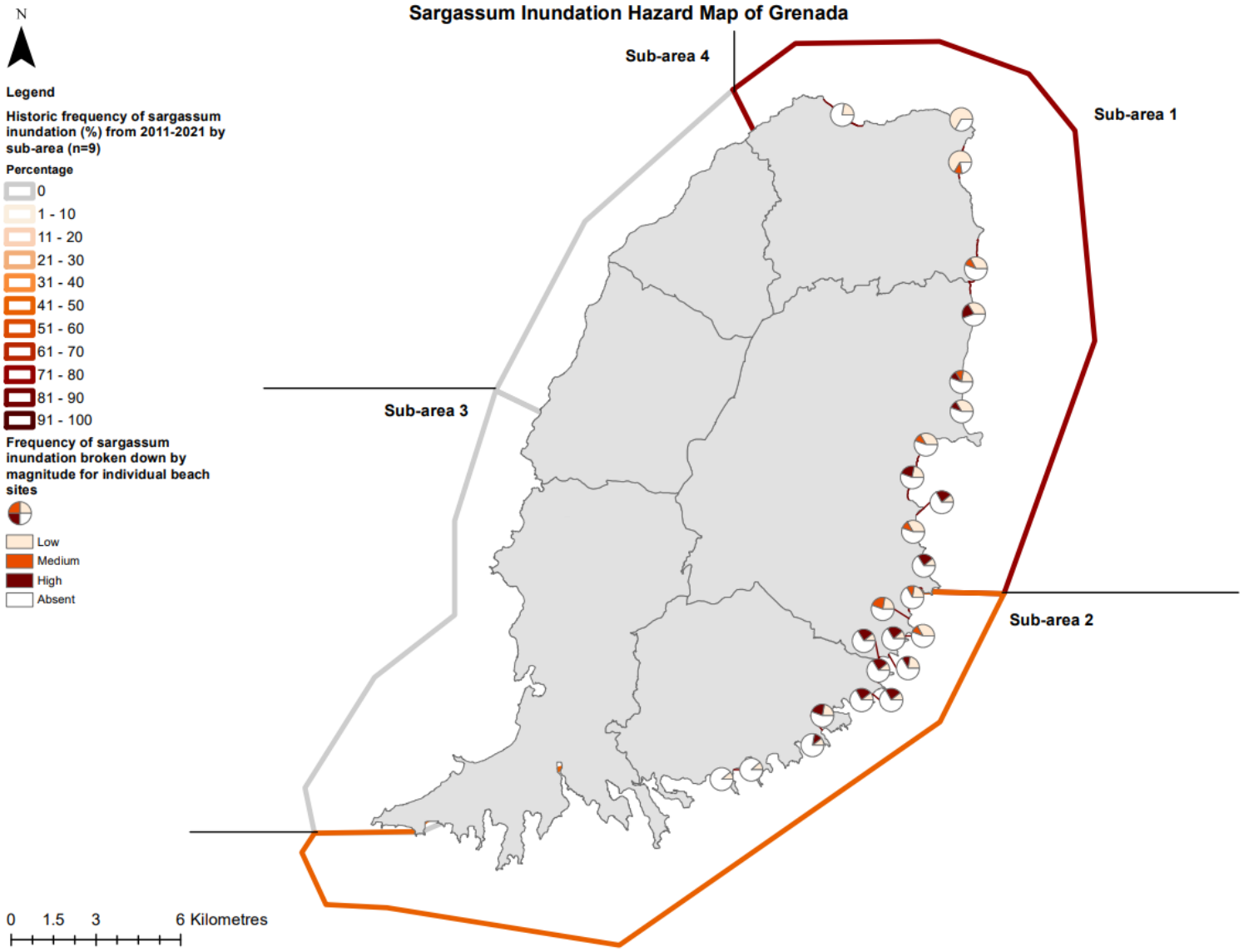

Figure 20 Map of Grenada showing the level of sargassum inundations by the four coastal sub-areas and at 25 exposed beaches

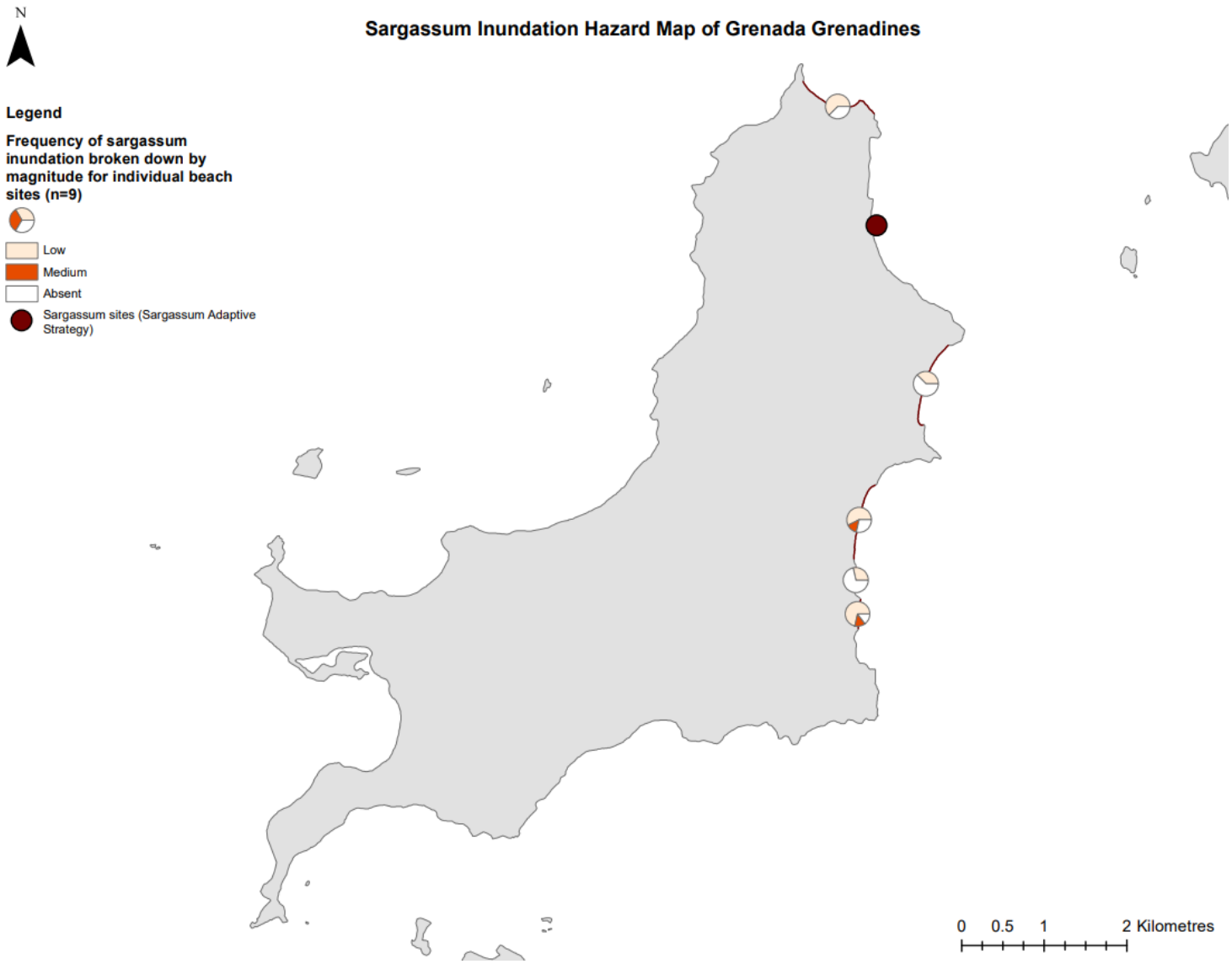

Figure 21 Map of Grenada Grenadines (Carriacou) showing the level of sargassum inundations at four exposed beaches and the location of one SAMS site

Ecosystem exposure

Ecosystems assets for Grenada and its Grenadines (Carriacou) are represented by a pre-existing marine benthic habitats layer showing 4 categories (coral/algae, sand, seagrass dense, seagrass sparse), coastal habitats (mangroves, rocky beaches, coastal springs, coastal lagoons, black sand beaches, white sand beaches) sea bird nesting sites, sea turtle nesting sites and wetlands.

The most commonly exposed ecosystem is that of rocky beaches which occur around most of the islands. Black sandy beaches and white sandy beaches are also exposed to sargassum inundation. Among the many ecosystem services of beaches is provision of suitable nesting sites for endangered sea turtles. On the mainland, most of the leatherback nesting sites are located on the north and northeast coasts of the island which have a high level of exposure to sargassum inundation (Figure 22). Meanwhile in Carriacou, leatherback nesting sites on the north coast and hawksbill nesting sites on the east coast are exposed to sargassum inundation (Figure 23). Migratory shorebirds also rely on beaches and coastal wetlands (including 'bird swamps', brackish ponds and mangroves) for forage and shelter; however, none of these areas are exposed. Several mangroves, located on the windward side of the island (north to south coasts) and on the north coast of Carriacou are exposed to sargassum inundations. Three in particular, Levera and Conference on the mainland and Petit Carenage on Carriacou are main mangrove areas which are exposed to sargassum inundation.

Shallow shelf patch reefs are located all around the islands (Figure 22, Figure 23) and those found on the windward side of islands are potentially exposed to sargassum inundation depending on the distance from shore. Similarly, seagrass associated with hard coral reef is also exposed to sargassum inundation, depending on the distance from shore.

The main island has four marine designated areas while Carriacou has one and they are located on the south and southwest coasts which are not exposed to sargassum inundation (Figure 22, Figure 23).

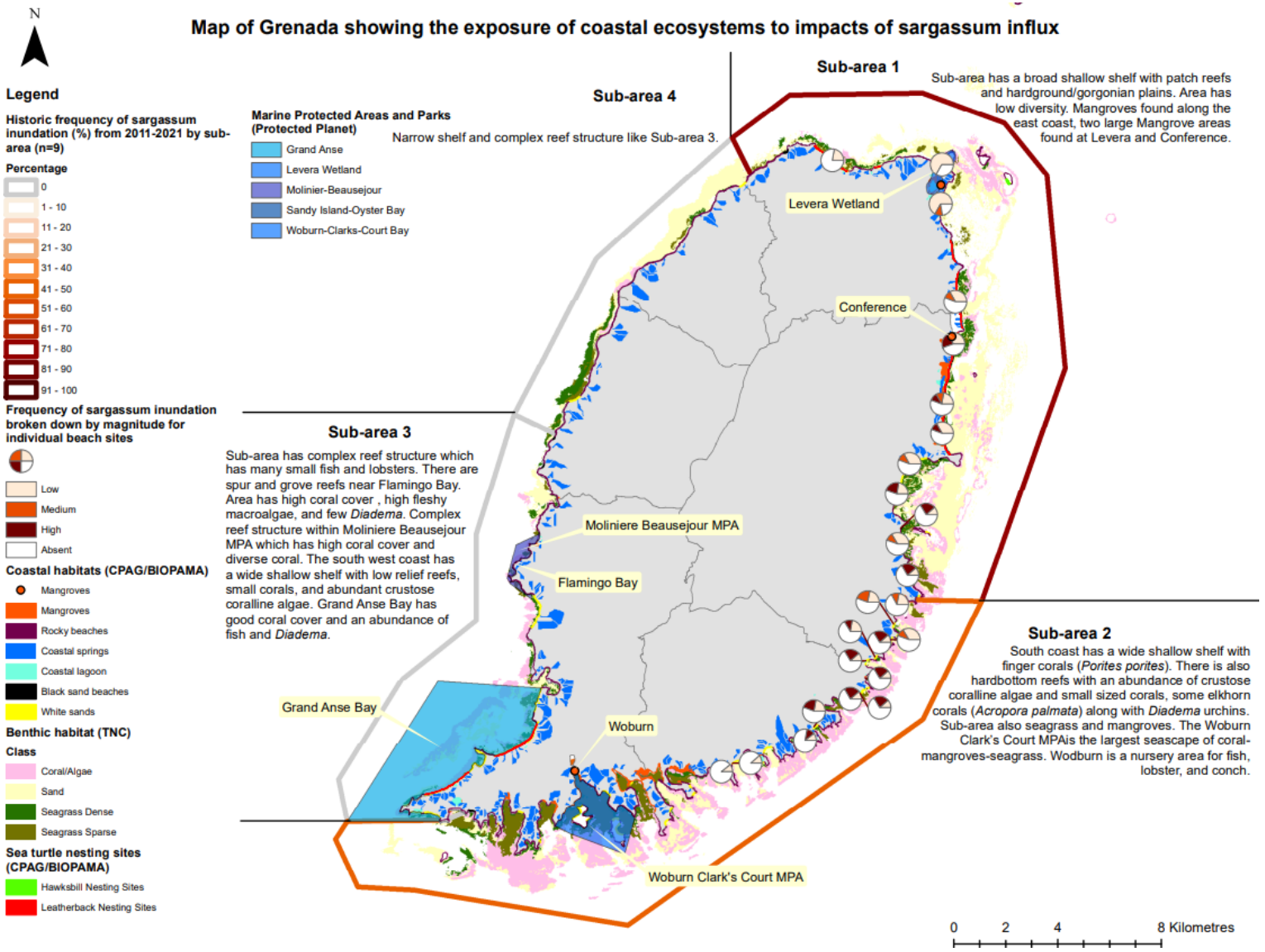

Figure 22 Map of Grenada showing the exposure of coastal ecosystems to sargassum inundation

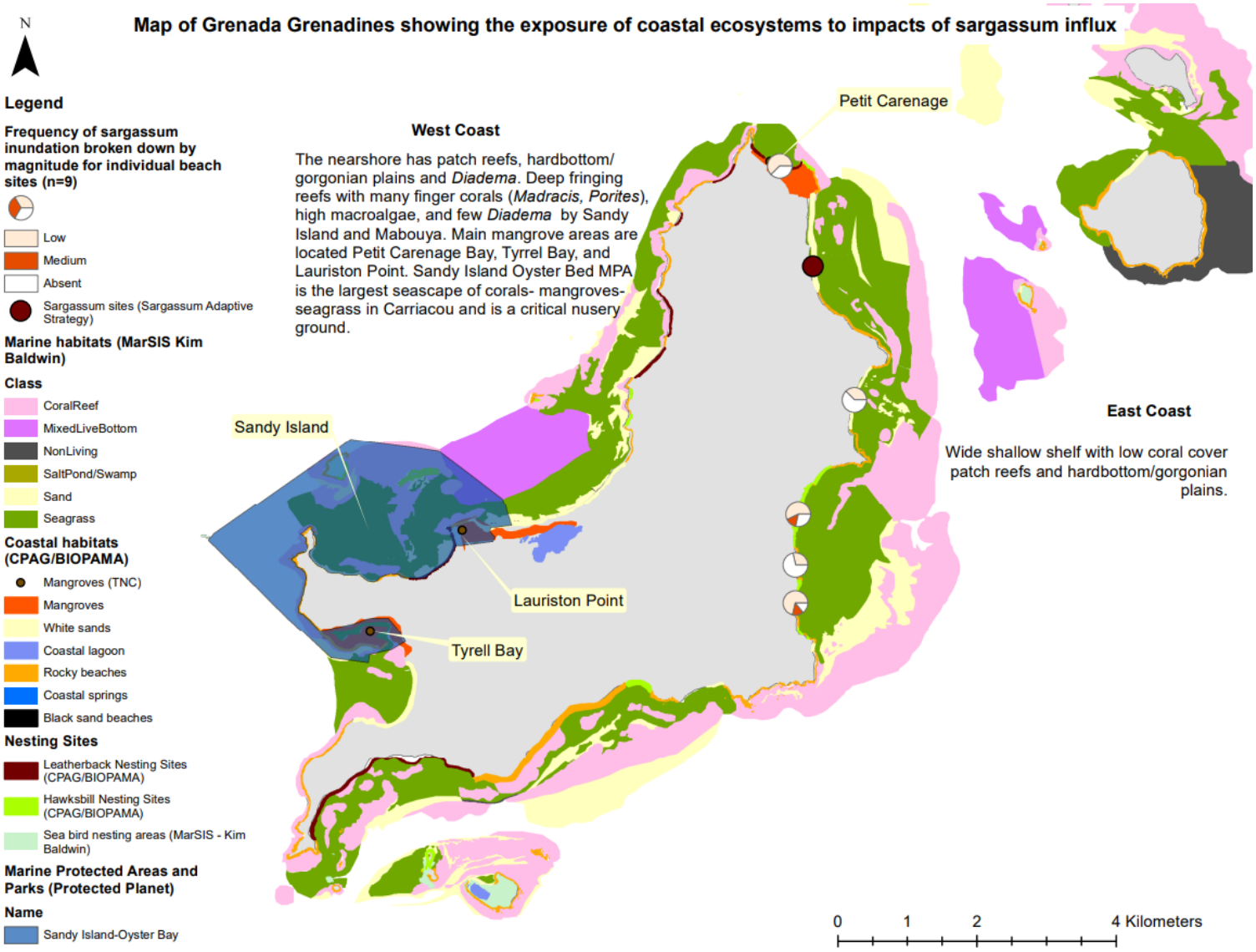

Figure 23 Map of Grenada Grenadines (Carriacou) showing the exposure of coastal ecosystems to sargassum inundation

Tourism

In Grenada, many beach-front and nearshore tourism assets are located on the southwest and south coasts of the main island. Those assets on the southwest coast are not directly exposed to sargassum inundation; however, a few on the south coast experience low exposure and the few on the north and east coasts are also exposed (Figure 24). These coastal tourism assets include hotels, resorts, anchorages and jetties. There are also tourism assets on the southeast coast, albeit of lower density. Pearls Airport, which is no longer functional, is exposed to frequent inundations of sargassum.

In Carriacou, assets are mainly on the west coast of the island which is not exposed sargassum inundation. Those on the north and northeast coasts are exposed to sargassum inundation. Exposed assets include hotels, recreational areas and water taxi operators (Figure 25).

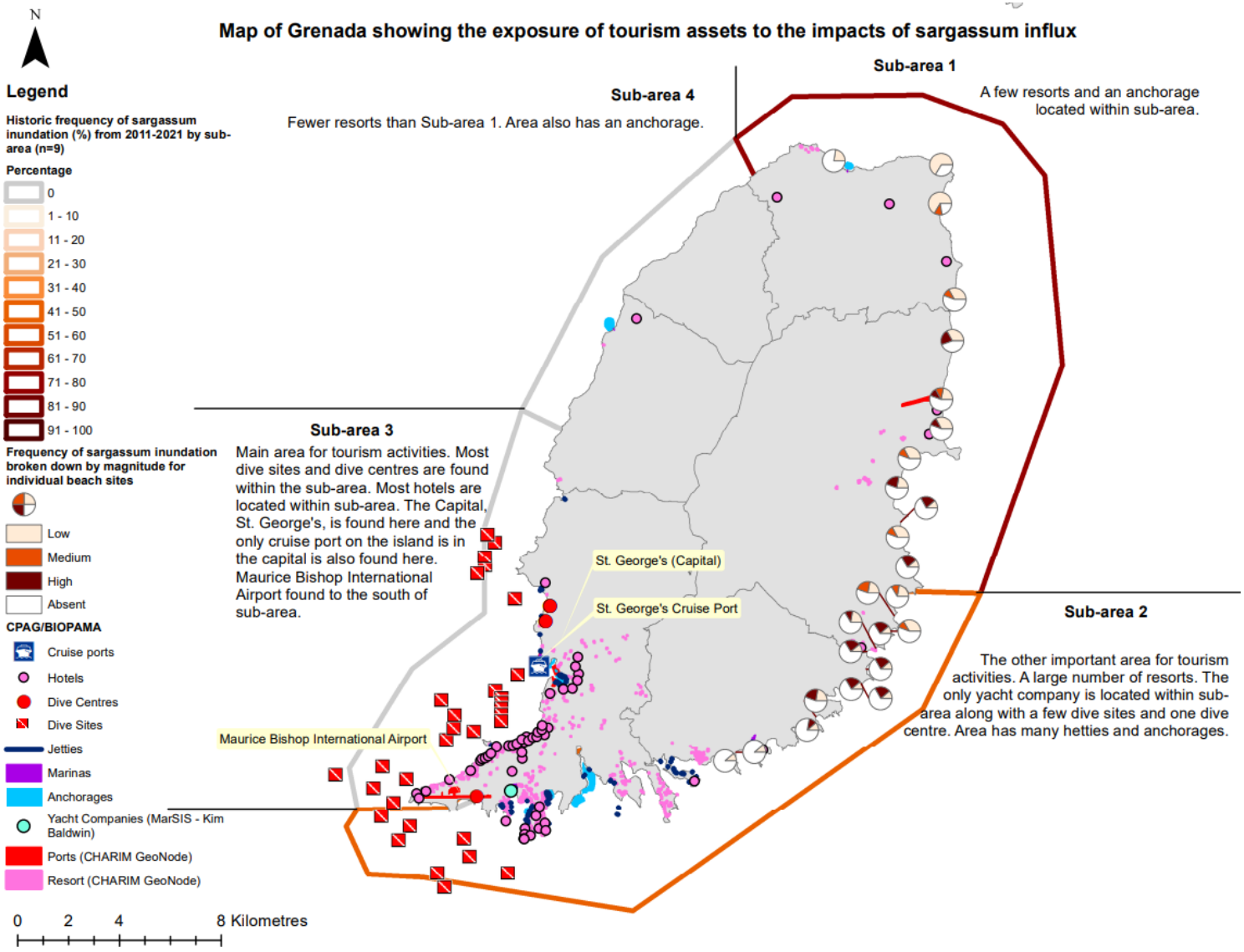

Figure 24. Map of Grenada showing the exposure of tourism assets to sargassum inundation

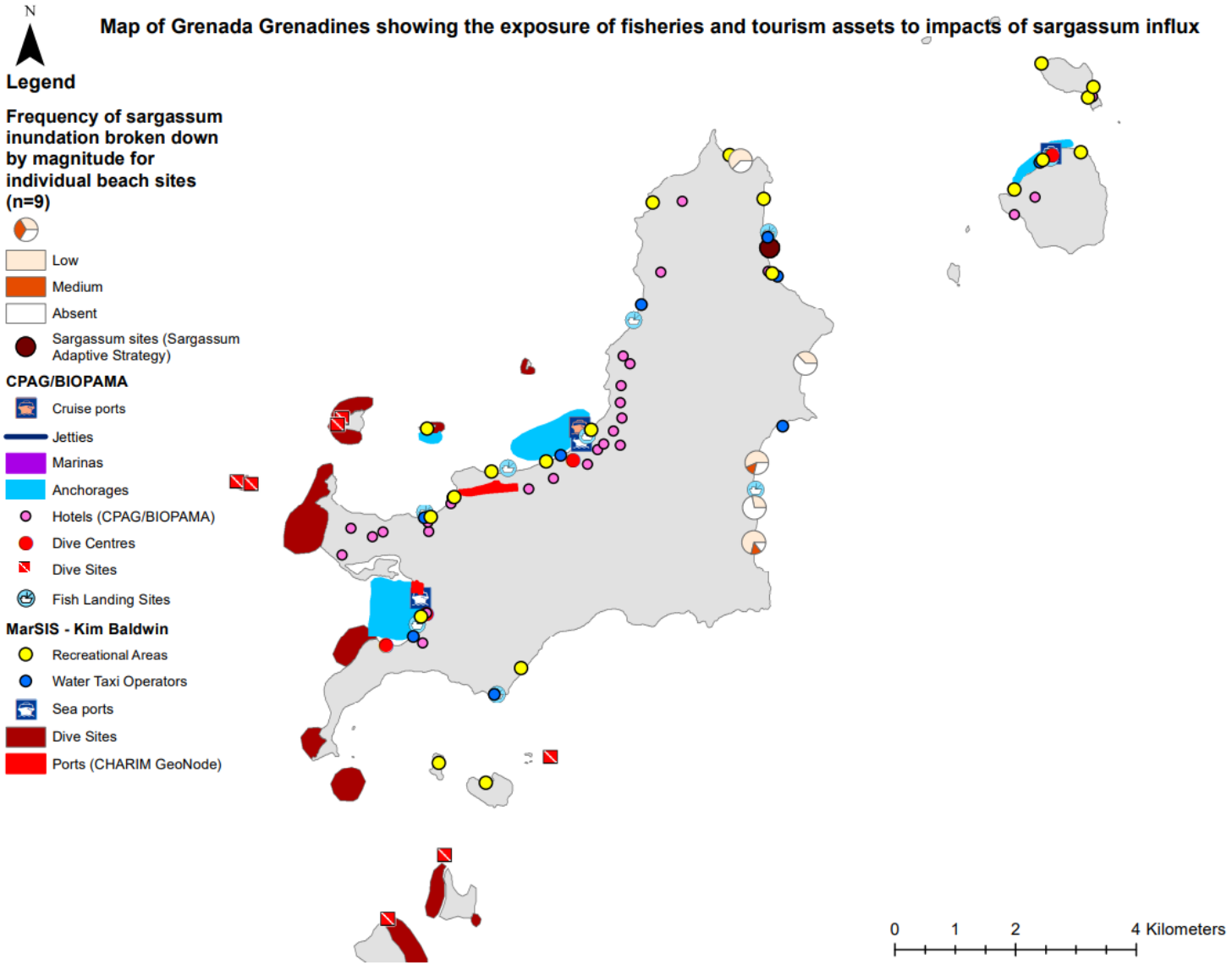

Figure 25 Map of Grenada Grenadines (Carriacou) showing the exposure of tourism and fisheries assets to sargassum inundation

Fisheries exposure

Grenada and its Grenadines have 30 officially designated fish landing sites, 25 on the mainland and five on Carriacou. On the mainland, most of these are located on the west and southwest coasts of the island with no exposure to sargassum inundation (Figure 26). However, there are six landing sites on the windward coasts that are exposed to sargassum inundation (Figure 26, Table 12). In Carriacou, only two fish landing sites are exposed Table 12). Two primary fish landing sites, Sauteurs and Grenville, have significant fishery infrastructure including market facilities, jetties, moorings and haul-out areas which would be exposed. These highly exposed fish landing sites tend to focus on shallow reef fisheries including lobster and sea urchins, and nearshore small pelagic species. Grenville in particular has the highest percentage of fish landings (Figure 26).

Table 12. Number of fish landing sites by coastal zone sub-area (CZSA) in Grenada and Carriacou and the names of fish landing sites exposed to sargassum inundations.

CZSA	Number of fish landing sites	Names of sites exposed
1	3	Sauteurs
		Conference
		Grenville
2	5	Crochu/Mahot
		Requin
		Petite Becaye
3	9	-
4	6	-
Carriacou	5	Windward
		Grand Bay/Mount Pleasant

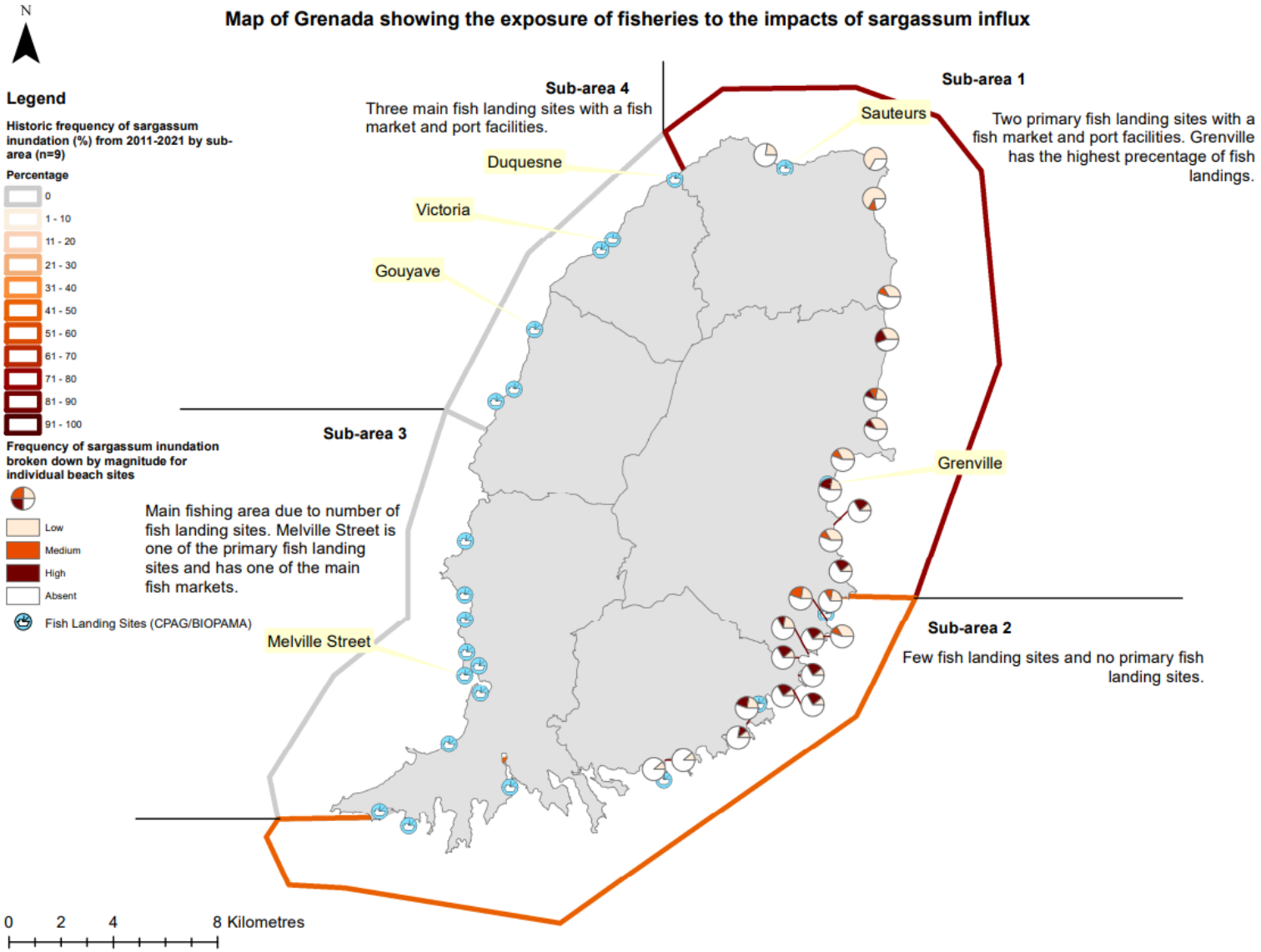

Figure 26 Map of Grenada showing the exposure of fisheries assets to sargassum inundation

Dominica

Spatial Distribution of Hazard Frequency and Magnitude

Based on available Google Earth imagery from 2010 to 2021, beaches exposed to sargassum inundation make up 21 km (14%) of the coastline of Dominica mainland. This was further examined for the six CZSAs. Of these, only sub-areas 1 to 4 have been exposed to sargassum inundations over the years (Figure 28, Table 13). Sargassum inundations occur mainly on the southeast, east, northeast and north coasts (Figure 28). The magnitude and frequency of inundations are similar among the sub-areas, with sub-area 1 to 3 experiencing sargassum 29% of the time while sub-area 4 experiences sargassum 21% of the time (Figure 28, Table 13). Even though the sub-area 1 and 3 have almost the same number of beaches, sub-area 3 has the greater length of exposed coastline (8.48 km) (Table 13). At a higher spatial resolution, the magnitude and frequency of inundations also varies among the 33 beaches within sub-areas. Exposed beaches within sub-areas 2 and 3 experience higher levels of inundations than exposed beaches in other sub-areas. Several exposed areas including Walker's Rest Bay, Sophia Bay, and Good Hope North experience high sargassum inundations > 20% of the time (

Table 14, Figure 27).

Table 13. Sargassum inundation frequency, number of exposed beaches, and length of exposed shoreline by coastal zone sub-area (CSZA) in Dominica. Frequency is shown as % of all available images.

CZSA	Presence of sargassum (%)	Number of exposed beaches	Length of exposed beach (km)
1	29	12	6.91
2	29	7	3.45
3	29	10	8.48
4	21	4	2.0
5	0	0	-
6	0	0	-
Total		**33**	**20.84**

Table 14 Frequency and magnitude of sargassum inundations for individual beach sites by coastal zone sub-area (CZSA) in Dominica. Frequency is shown as % of all available images. Highlighted boxes indicate sites with the greatest frequency (> 20%) of high-magnitude exposure. Sub-areas 5 and 6 are not exposed to sargassum and therefore not represented here.

CZSA	Name of exposed shoreline	Site ID	Level of sargassum inundation (%)				Length of exposed shoreline (m)
			Low	Medium	High	Absent	
1	Thibaud	1.1	4	0	0	96	211
	Blenheim	1.2	4	0	0	96	164
	Anse de Mai	1.3	4	0	0	96	686
	Batibou Beach	1.4	4	0	0	96	366
	Hampstead	1.5	4	0	0	96	497
	Calibishie	1.6	4	0	0	96	1,049
	Woodford Hill	1.7	17	4	4	75	650
	La Taille Bay North	1.8	21	0	0	79	285
	La Taille Bay South	1.9	8	0	0	92	834
	Walker's Rest Bay	1.10	8	0	21	71	207
	Sophia Bay	1.11	8	0	21	71	157
	Londondery Bay	1.12	4	4	13	79	1,804

2	Mango Hole Bay	2.1	8	0	8	83	489
	Mango Hole Inland	2.2	13	0	13	75	363
	Atkinson	2.3	8	8	8	75	459
	Ravine Benoit North	2.4	8	8	8	75	769
	Raymond Bay	2.5	8	13	8	71	452
	Richmond Bay North	2.6	13	8	8	71	291
	Richmond Bay South	2.7	8	4	17	71	631
3	Castle Bruce	3.1	8	4	17	71	922
	Good Hope North	3.2	8	0	21	71	202
	Good Hope South	3.3	4	17	8	71	467
	Rosalie	3.4	13	0	17	71	1,129
	Boute Sabe Beach	3.5	13	0	17	71	686
	Case O' Gowrie	3.6	17	0	0	83	1,202
	Plaisance	3.7	8	0	8	83	597
	Laronde	3.8	4	0	8	88	836
	Delices	3.9	4	0	8	88	1,500
	Fond St. Jean	3.10	8	0	0	92	935
4	Dubuc	4.1	4	0	0	96	232
	Berekua	4.2	21	0	0	79	1,063
	St. Patrick Boundary	4.3	13	0	0	88	483
	St. Mark	4.4	8	0	0	92	218

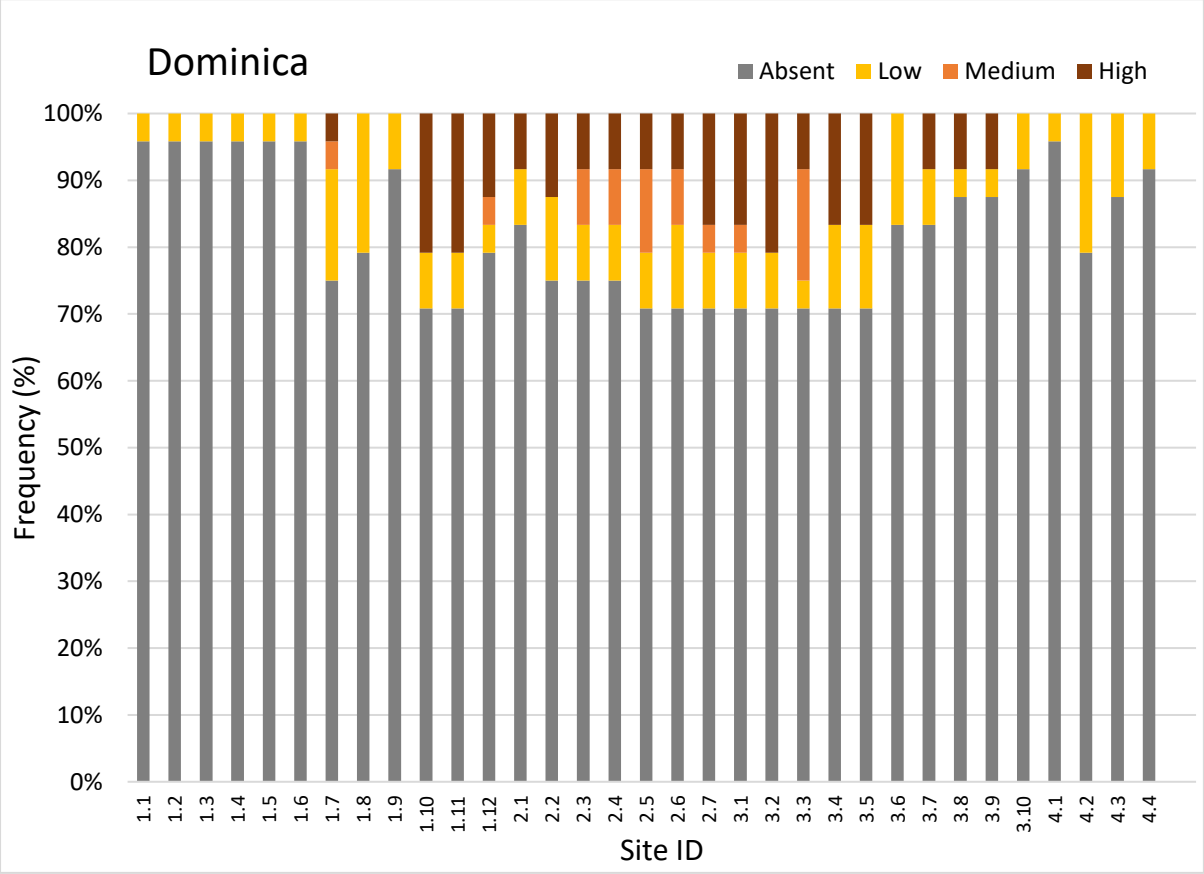

Figure 27 Frequency of sargassum inundations by magnitude in Dominica. Site names given in Table 14.

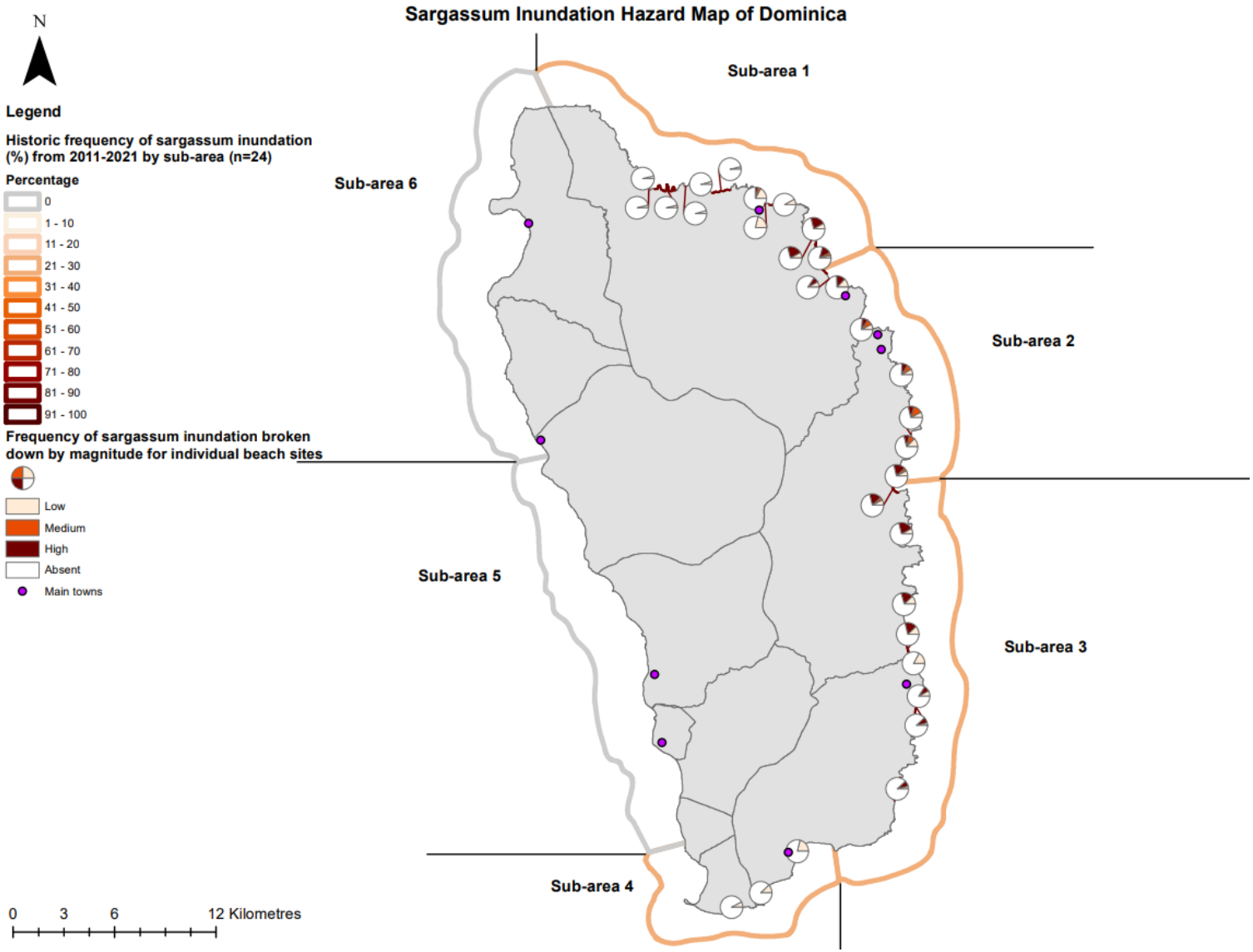

Figure 28. Map of Dominica showing the level of sargassum inundations by the four coastal sub-areas and at 33 exposed beaches

Ecosystem exposure

Ecosystems assets for Dominica are represented by a pre-existing marine benthic habitats layer showing 10 categories (boulders and rocks, coral/algae, hardbottom dense algae, hardbottom sparse algae, reef back reef crest, reef fore, sand, seagrass dense, and seagrass sparse), bays, sea turtle nesting sites and wetlands.

The most widely exposed ecosystem is that of sandy beaches which occur around most of the island. Many bays on the windward coasts are exposed to sargassum inundation. Among the many ecosystem services of beaches is provision of suitable nesting sites for endangered sea turtles. The nesting sites are located all around the island except for the south coast and those located on the windward side of the island are exposed to sargassum inundation (Figure 29). There are a few mangroves located on the island; however, only Boute Sable Mangrove on the southeast coast in sub-area 3 is exposed to sargassum inundation. Cabrits and Indian River mangroves are located along the northwest coast which is not exposed to sargassum inundation.

Hard coral reefs and associated soft coral habitats are located in small patches around the island; however, sub-area 2 has no major reefs. The largest reefs which are complex and diverse are found on the northeast coast which is subject to low frequency of sargassum inundations. Coral reefs located in the eastern part of sub-area 3 are exposed to sargassum inundations that are usually high in magnitude. The northwest coast has critically important reefs; however, this coast is not exposed to sargassum inundations (Figure 29). Seagrass is abundant around the island; fortunately, most of it is located on the leeward side which is not exposed to sargassum inundation (Figure 29).

The island has three marine designated areas, Cabrits and Indian River are located on the northwest coast and therefore not exposed to sargassum inundation, and Soufriere/Scott's Head is located on the south coast around an area with low exposure to sargassum (Figure 29).

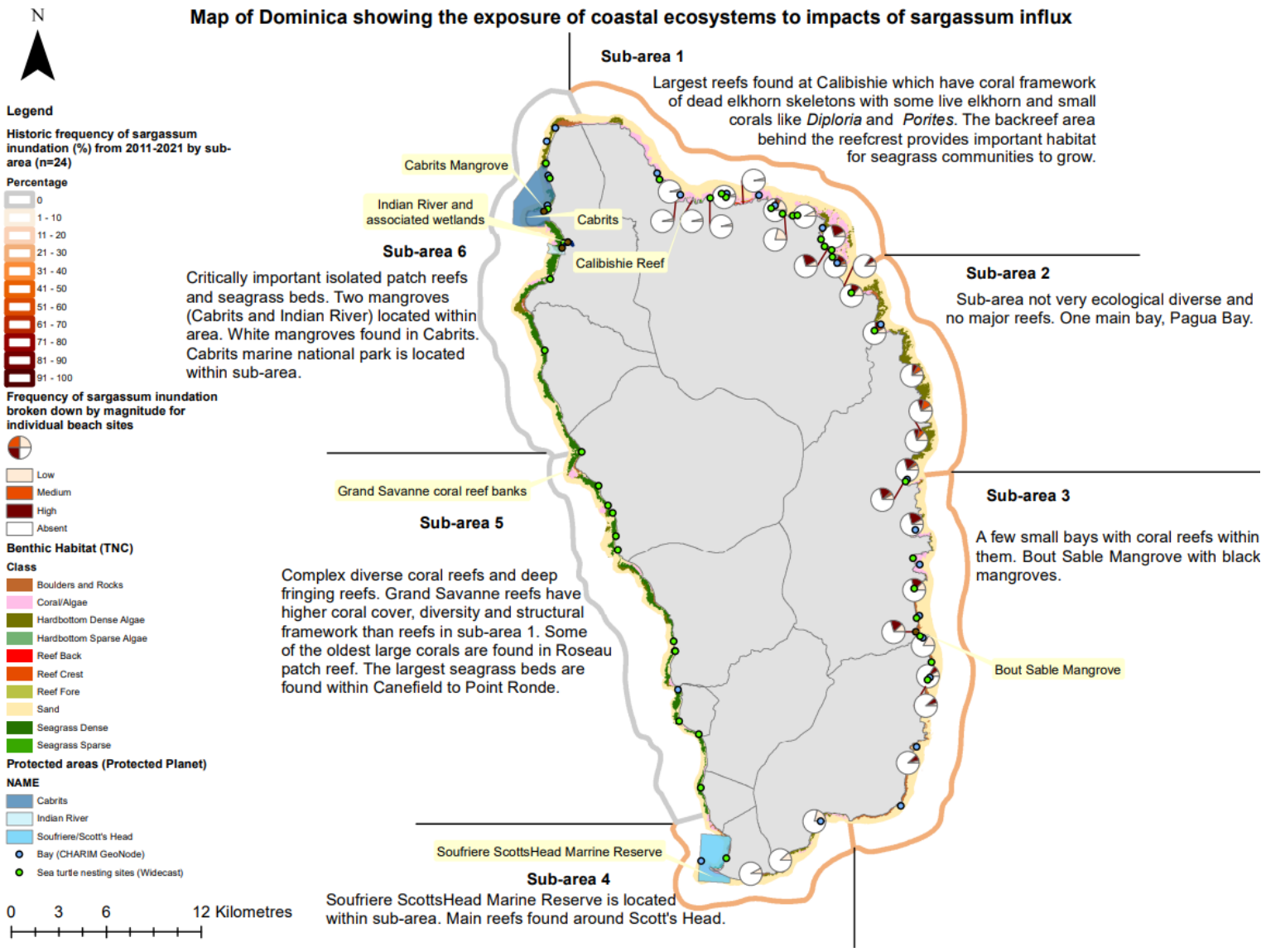

Figure 29 Map of Dominica showing the exposure of coastal ecosystems to sargassum inundation

Fisheries

Dominica has 34 officially designated fish landing sites. Most of these are located on the northwest, west and southwest coasts of the island with no or relatively low exposure to sargassum inundation (Figure 4). However, there are eight landing sites on the southeast and east coasts that are exposed to sargassum inundation (Figure 30,

Table 16). Anse de Mai and Castle Bruce are two primary landing sites that exposed to sargassum inundation (

Table 16). The landing sites that are exposed in sub-area 1 are exposed to infrequent inundations of sargassum while those in sub-area 2 and sub-area 3 are exposed to higher magnitude of sargassum inundations. The fish landing site with the largest recorded fish catch, Marigot, is one of the fish landing sites in sub-area 2 that is exposed to sargassum inundations. Most of the fish landing sites that are monitored for fish catch are not exposed to sargassum as they are located on the leeward side of the island (Table 15).

Table 15 The average annual (2018 -2020) total recorded fish landings for the 13 monitored fish landing sites in Dominica

CZSA	Landing Site	Landings (t)
2	Marigot	232.9
3	Fond St. Jean	25.3
	SanSaveur	47.3
4	Scotts Head	77.1
5	Fond Cole	35.6
	Layou	47.1
	Pottersville	23.7
	Salisbury	20.1
	St. Joseph	18.5
6	Bioche	7.3
	Colihaut	51.6
	Dublanc	70.4
	Portsmouth	163.8
Grand Total		820.7

Table 16. Number of fish landing sites by coastal zone sub-area (CZSA)in Dominica and the names of fish landing sites exposed to sargassum inundations.

CZSA	Number of fish landing sites	Names of sites exposed
1	4	Anse de Maie
		Calibishie
		Woodford Hill
2	1	Marigot
3	3	Castle Bruce
		San Sauveur
		Fond St. Jean
4	3	Stowe
5	15	
6	8	

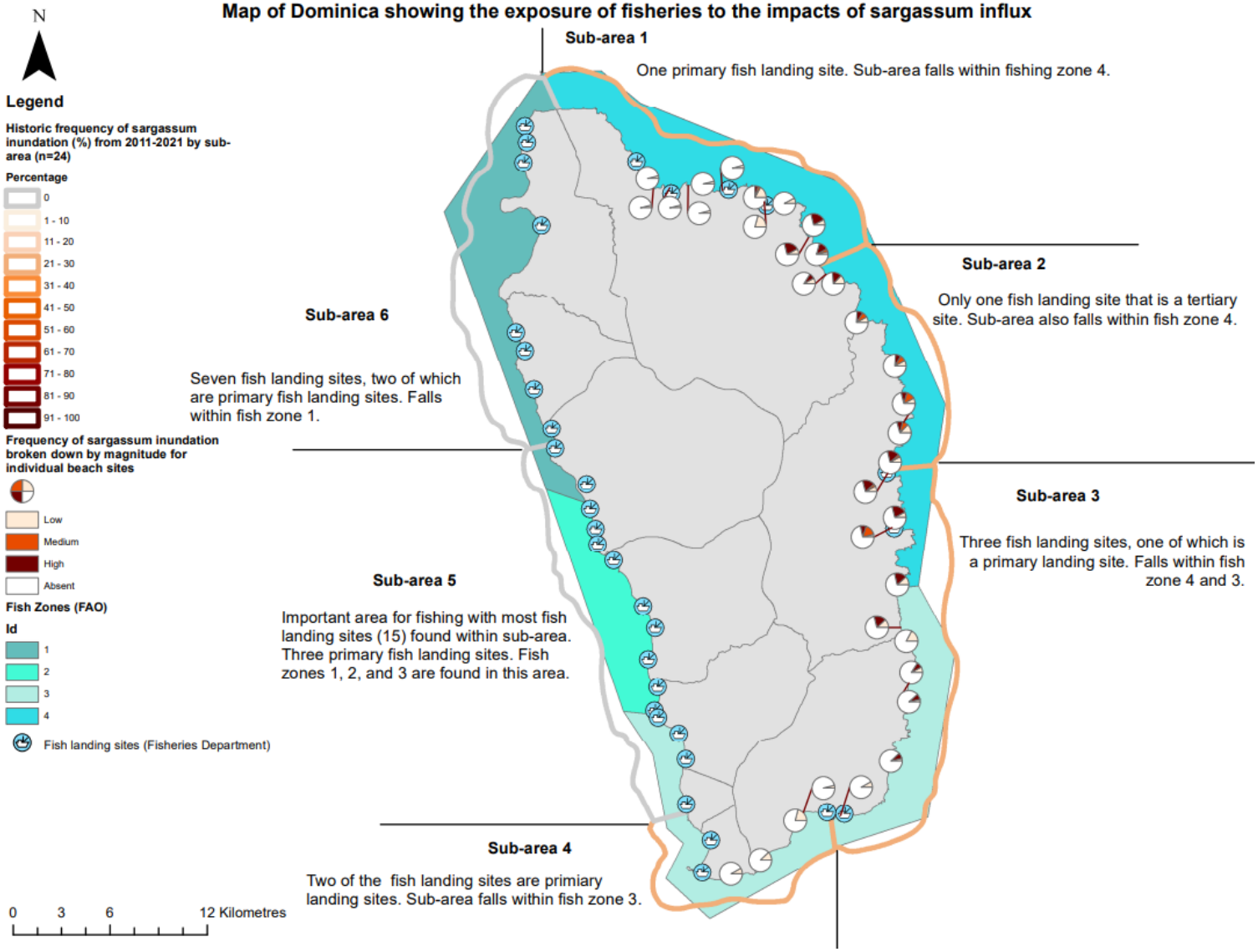

Figure 30 Map of Dominica showing the exposure of fisheries assets to sargassum inundation

St. Vincent and the Grenadines

Spatial Distribution of Hazard Frequency and Magnitude

Based on available Google Earth imagery from 2010 to 2021, beaches exposed to sargassum inundation make up 16.79 km (20 %) of the coastline of St. Vincent mainland. This was further examined for the five CZSAs. Of these, all except sub-area 3 have been exposed to sargassum inundations over the years (Figure 32, Table 17). However, previous surveys conducted for the development of a Sargassum Adaptive Management Strategy (SAMS) show that at least two areas in sub-area 3 have been exposed to sargassum. Sargassum inundations occur mainly on the southeast, east and northeast coasts, and to a lesser extent on the southwest coast on the mainland (Figure 32). The magnitude and frequency of inundations vary slightly among sub-areas, with sub-areas 1, 2 and 5 being the most exposed, receiving sargassum 33% of the time (Table 17). This contrasts with sub-area 4 (west coast) that receives sargassum just 17% of the time (Figure 32, Table 17). It is important to note that the inundations that occur in sub-area 5 occur on the northern/north-eastern coast and not on the north-western coast. Sub-area 2 has the highest number of exposed beaches (14) and greatest length of exposed shoreline (8 km); however, this is only slightly more than sub-area 1 (7.46 km) that has half the number of exposed beaches (Table 17). At a higher spatial resolution, the level of inundations is basically the same at the 25 beaches within sub-areas. Most beaches experience high inundation when they are exposed to sargassum (Figure 31, Table 18). Some of the minor islands, Bequia, Isle A Quatre, Mustique and Union Island, are also exposed to sargassum (Table 17). Sargassum mainly occurs on the windward side of all of the islands expect for Bequia which experiences sargassum inundations all along the shoreline (Figure 33). Overall, there are 6 beaches exposed on these islands (Table 17). However, SAMS surveys show another 11 are exposed.

There are several coastal towns located on the mainland; however, only Barroullie and Georgetown are exposed to sargassum inundations. Along with towns, there are coastal communities and all the key coastal communities on the mainland and on the minor islands are exposed to sargassum inundations based on Google Earth data and SAMS surveys.

Table 17. Sargassum inundation frequency, number of exposed beaches, and length of exposed shoreline by coastal zone sub-area (CZSA) in mainland St Vincent and the Grenadines. Frequency is shown as % of all available images.

CZSA	Presence of sargassum (%)	Number of exposed beaches	Length of exposed beach (km)
1	33	7	7.46
2	33	14	8.0
3	0	0	-
4	17	1	0.70
5	33	3	0.63
Bequia	33	1	0.27
Isle A Quatre	50	1	0.24
Mustique	25	4	1.71
Total		**31**	**19.01**

Table 18 Frequency and magnitude of sargassum inundations for individual beach sites by coastal zone sub-area (CZSA) in St. Vincent and the Grenadines. Frequency is shown as % of all available images. Highlighted boxes indicate sites with the greatest frequency (> 30%) of high-magnitude exposure. Sub-area 3 not exposed to sargassum and therefore not represented here.

CZSA	Name of exposed shoreline	Site ID	Level of sargassum inundation				Length of exposed shoreline (m)
			Low	Medium	High	Absent	
1	New Sandy Bay	1.1	0	17	17	67	1,571
	Windward 2	1.2	17	0	17	67	990
	Orange Hill North	1.3	0	0	33	67	229
	Orange Hill South	1.4	0	17	17	67	1,155
	Chapmans	1.5	17	0	17	67	922
	Georgetown	1.6	0	0	33	67	796
	Black Point	1.7	0	0	33	67	1,798
2	Byera	2.1	0	0	33	67	2,286
	Mount Grenan	2.2	0	0	33	67	139
	Friendly	2.3	0	0	33	67	497
	North Union - North	2.4	0	0	33	67	256
	North Union - South	2.5	0	0	33	67	260
	Windward 3	2.6	0	0	33	67	447
	Biabou - North	2.7	0	0	33	67	197
	Biabou - South	2.8	0	0	33	67	925
	Windward 4	2.9	17	0	17	67	235
	Windward 5	2.10	0	0	33	67	196
	Peruvian Vale	2.11	0	0	33	67	471
	Argyle	2.12	0	0	33	67	547
	Diamond	2.13	0	0	33	67	464
	Brighton	2.14	0	0	33	67	1,080
4	Barrouallie	B3	0	0	17	83	703
5	Owia North	IAQ	0	0	33	67	160
	Owia South	M1	17	0	17	67	268
	Windward 1	M2	0	0	33	67	198
Bequia	Hope Estate	M4	33	0	0	67	273
Isle A Quatre	Windward 1	M5	50	0	0	50	242
Mustique	Palm Beach	1.1	25	0	0	75	751
	Windsong	1.2	25	0	0	75	147
	Macaroni Beach	1.3	25	0	0	75	309
	Pasture Bay	1.4	0	0	25	75	505

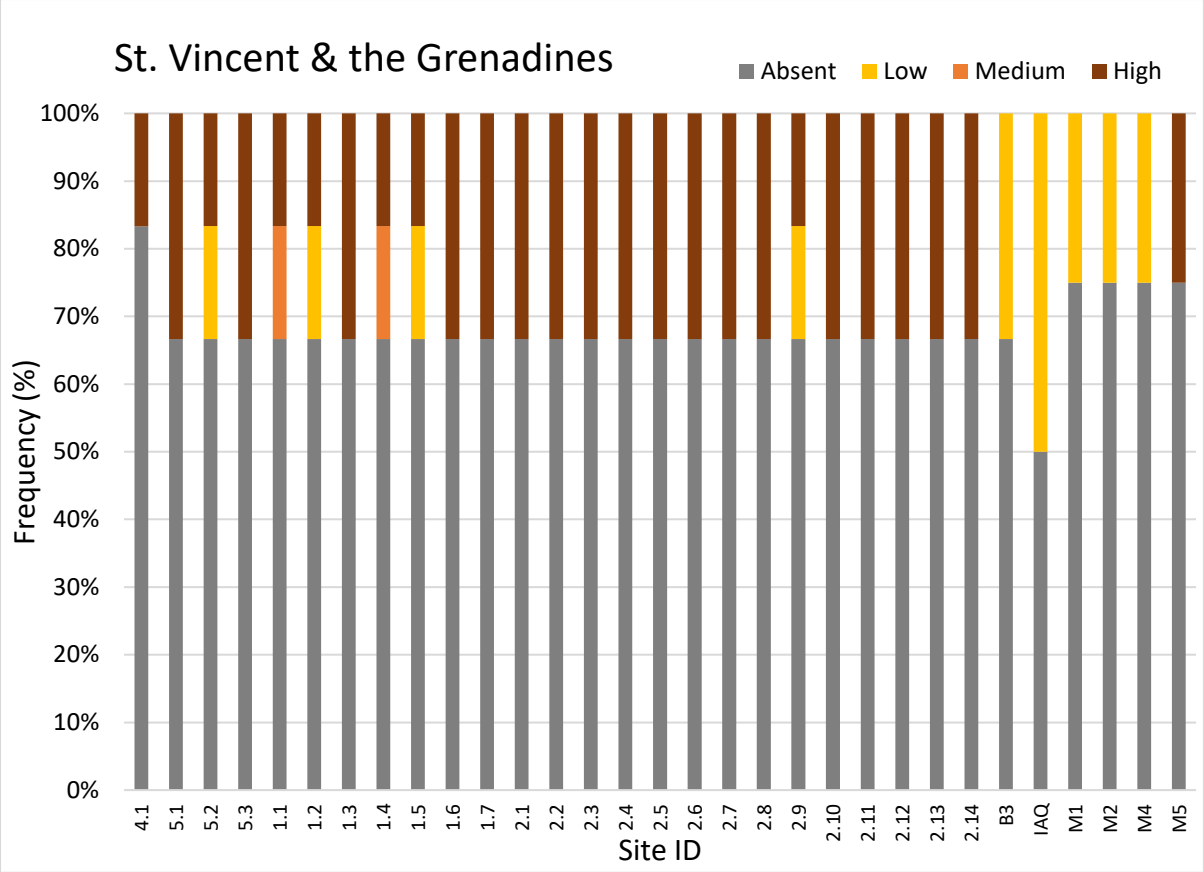

Figure 31 Frequency of sargassum inundations by magnitude in St Vincent and the Grenadines. Site names are given in Table 18.

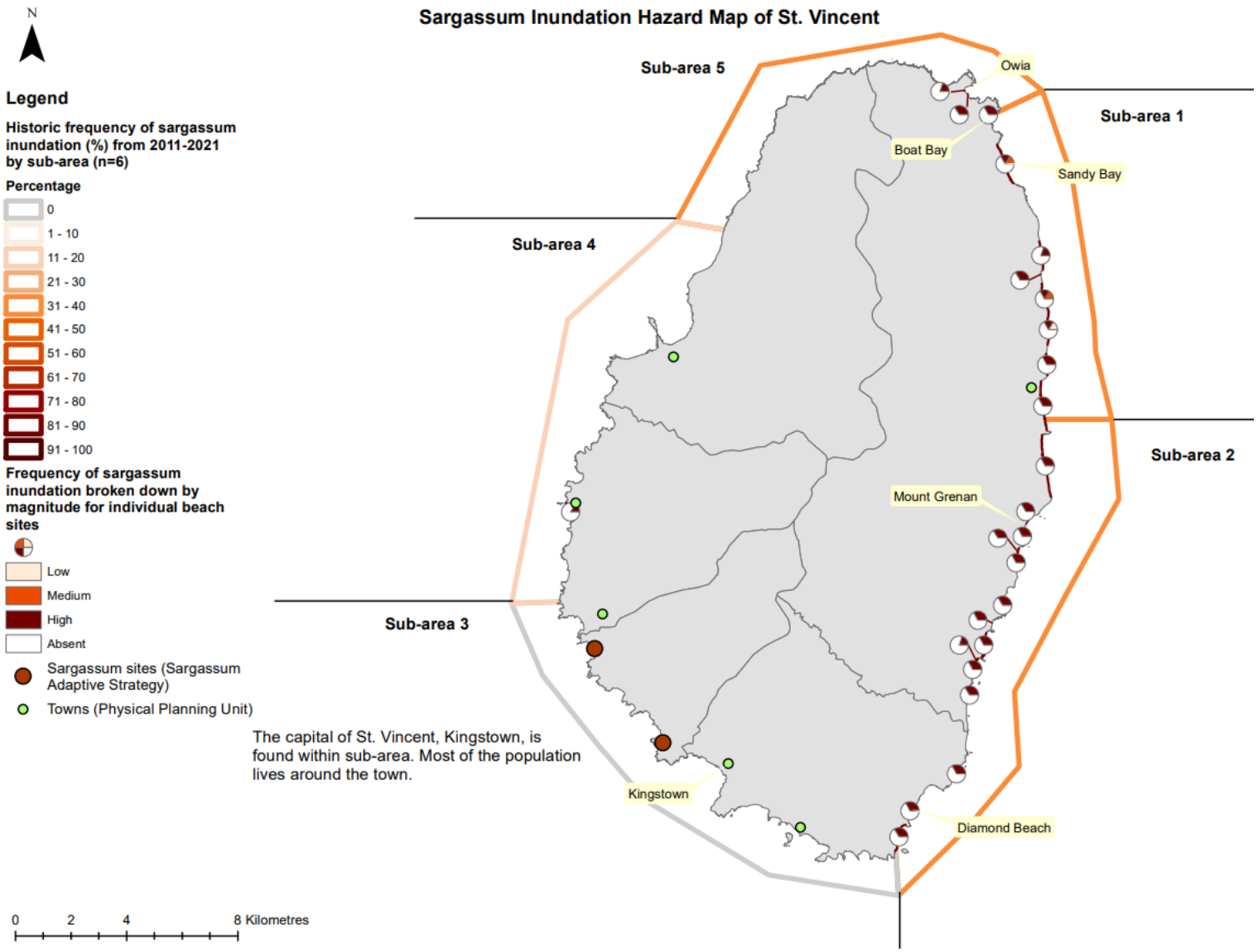

Figure 32. Map of St. Vincent showing the level of sargassum inundations by the four coastal sub-areas and at 25 exposed beaches

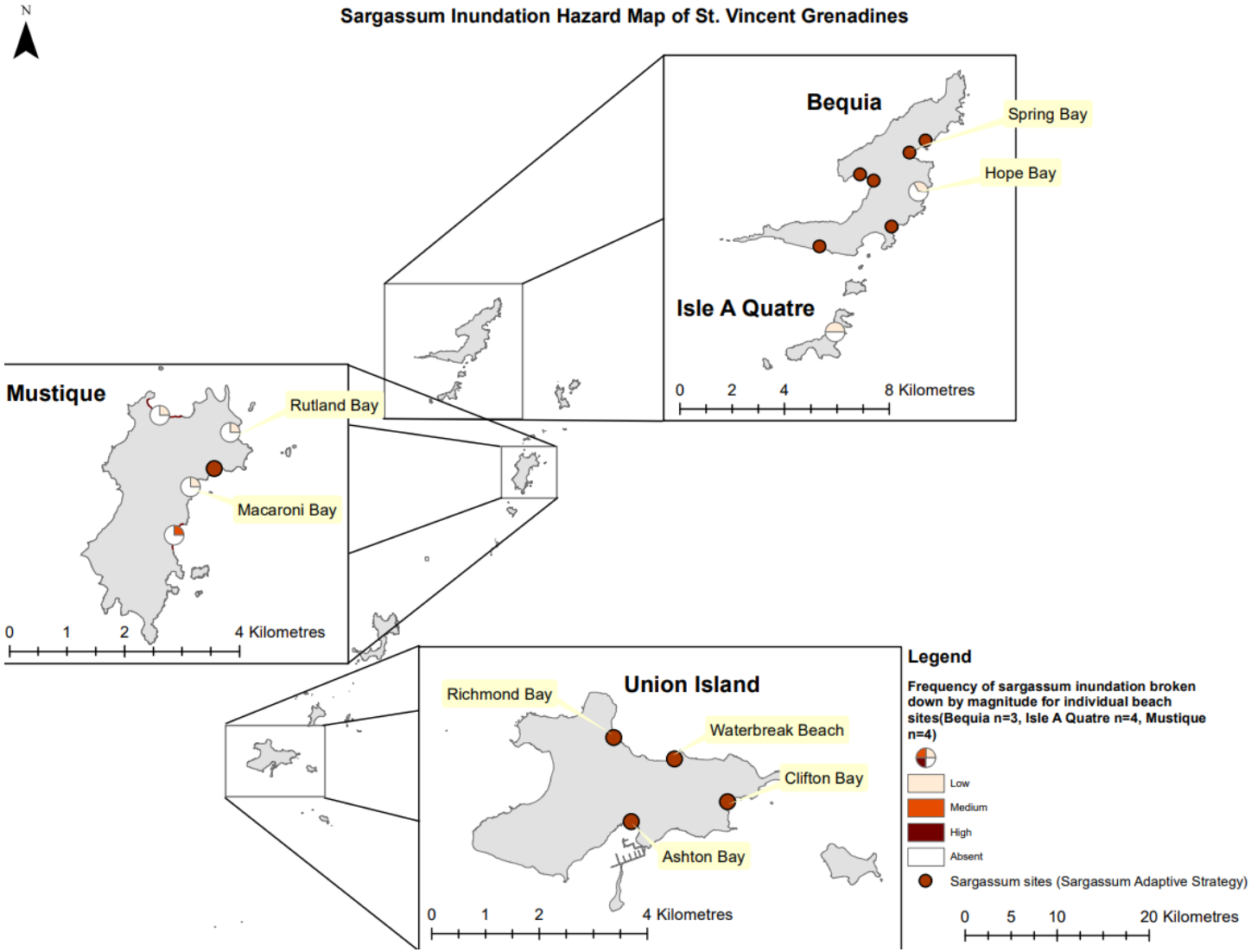

Figure 33. Map of St. Vincent Grenadines (Bequia, Isle A Quatre, Mustique, and Union Island) showing the level of sargassum inundations by the four coastal sub-areas and at 6 exposed beaches

Ecosystem exposure

Ecosystems assets for St. Vincent and its Grenadines are represented by a pre-existing marine benthic habitats layer showing 13 categories (boulders and rocks, coral/algae, hardbottom dense algae, hardbottom sparse algae, reef back reef crest, reef fore, mixed live bottom, non-living bottom, salt pond/swamp, sand, seagrass dense, and seagrass sparse), coastal habitats (white sand beaches, rocky beaches, coastal springs, and black sand beaches), bays, leatherback nesting sites, hawksbill nesting sites, seabird nesting sites and mangroves.

The most widely exposed ecosystem on the mainland is that of rocky beaches and black sand beaches which occur around most of the island, while on the minor islands it is mainly just rocky beaches (Figure 34, Figure 35). Among the many ecosystem services of beaches is provision of suitable nesting sites for endangered sea turtles. The nesting sites are located mainly on the windward side of the mainland and both leatherback and hawksbill nesting sites are exposed to high levels of sargassum inundations. On the minor islands, sea turtle nesting sites are found all around the island and both hawksbill and leatherback nesting sites are exposed to relatively low levels or sargassum inundations. Migratory shorebirds also rely on beaches and coastal wetlands (including 'bird swamps', brackish ponds and mangroves) for forage and shelter, and some resident species also forage, roost and nest on Union Island and Isle A Quatre and are exposed to sargassum inundations. There are a few mangroves on the mainland which are located along the south coast which is not exposed to sargassum. Meanwhile, mangroves are found on the windward side of Union Island and located in areas exposed to sargassum. There is a small area to the north of Mustique which is slightly exposed to sargassum inundations. The other mangrove areas on the island and on the other minor islands are not located in areas exposed to sargassum (Figure 33).

Hard coral reefs and associated soft coral habitats are located in patches all around the mainland; however, the windward side where sargassum inundation is high, coral cover and density is low (Figure 34). Hard coral reefs are also found around all of the minor islands and are therefore exposed to sargassum inundations depending on the distance from shore. Seagrass is also abundant in the minor islands and are also exposed to sargassum inundations (Figure 35). On the other hand, seagrass is scarce on the mainland but occurs in a few low-density meadows in small pockets along the west coast with low exposure sargassum inundations (Figure 34).

St. Vincent mainland has one marine designated area, South Coast Marine Conservation Area, located on the south coast and therefore not exposed to sargassum (Figure 34). There are many marine protected areas on the minor islands with the entire island of Mustique being designated as marine conservation area. There are also other marine conservation areas around the island as well as around the other minor island. Most of these protected areas are exposed to sargassum inundations except for one area on the leeward side of Mustique (Figure 35).

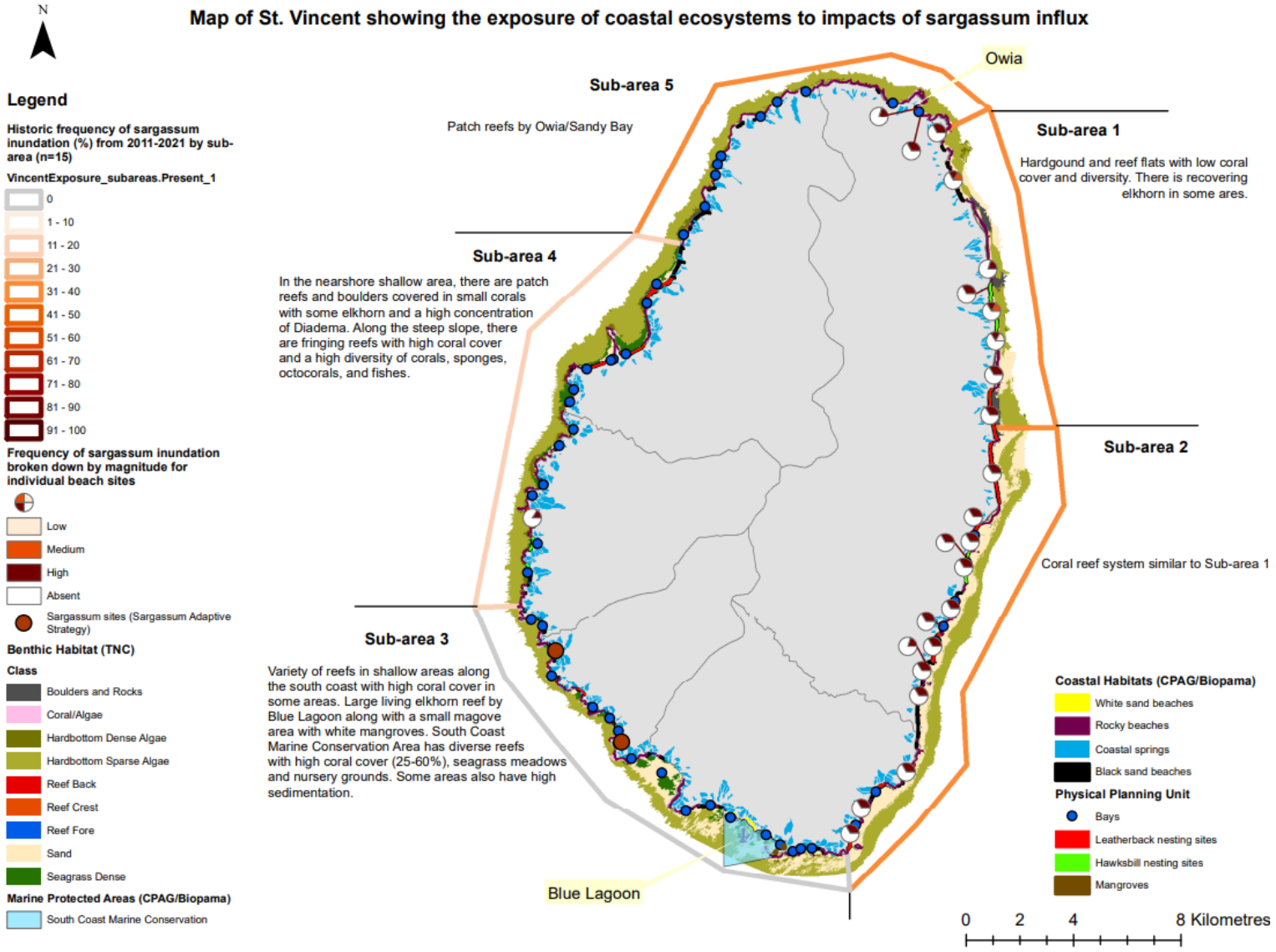

Figure 34. Map of St. Vincent showing the exposure of coastal ecosystems to sargassum inundation

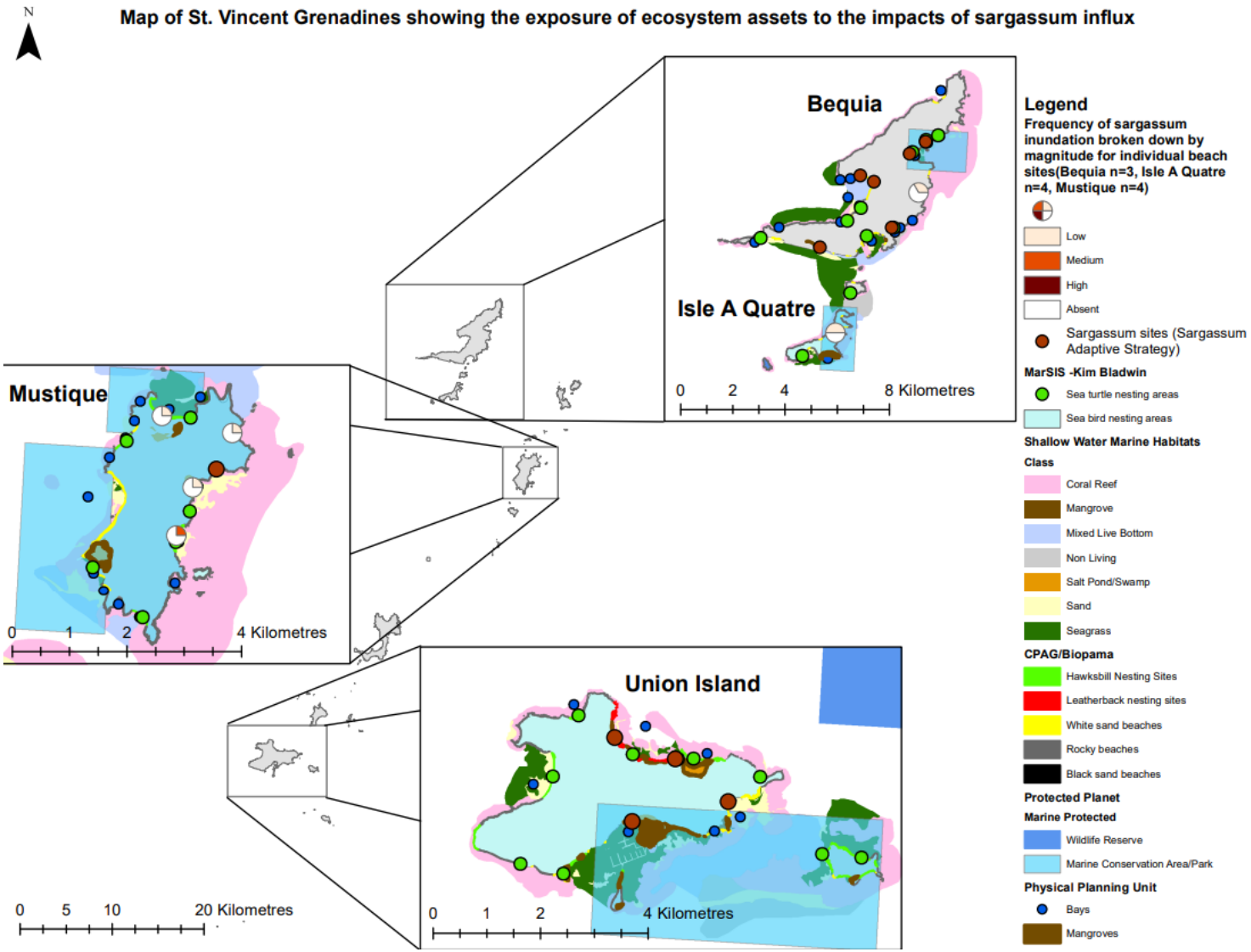

Figure 35 Map of St. Vincent Grenadines (Bequia, Isle A Quatre, Mustique, and Union Island) showing the exposure of coastal ecosystems to sargassum inundation

Tourism exposure

In St. Vincent and the Grenadines, there are many beach-front and nearshore tourism assets located on the south and southwest coasts of the mainland. These assets include hotels, yacht companies, ferry operators, dive centres, dive sites, and recreational areas. Fortunately, since these assets are located mainly on the south and southwest coasts, they are not generally exposed to sargassum inundation. However, dive sites and a few recreational areas in the Lowmans Bay area (SAMS site) are exposed to sargassum inundations. Recreational areas are also found on the windward side of the island and these areas generally have high levels of sargassum exposure (Figure 36).

Designated ship and yacht anchorages, marinas, jetties, seaports, and airports on the island are located on the south and southwest coasts which has no sargassum exposure except for the Lowmans Bay area. However, none of these assets are exposed to sargassum (Figure 36).

The Grenadines islands have many of the same types of tourism assets found on the mainland. However, many of these assets are exposed to sargassum inundation on these smaller islands (Figure 37). In Bequia, ferry operators, yacht companies, dive centres, an airport and seaport, anchorages, jetties, hotels, and recreational areas are all exposed to sargassum inundations at different areas around the island. Isle A Quatre on the other hand does not have many tourism assets and the few on the island are not located in the area that is exposed to sargassum inundations. Similarly, Mustique has a few tourism assets which are located mainly on the leeward side of the island while sargassum inundations occur on the windward side of the island, so the assets are not exposed to sargassum. Union Island also has fewer assets than Bequia; however, the seaport, a dive centre, recreational areas, a jetty and a few hotels are exposed to sargassum inundation on the windward side of the island (Figure 37).

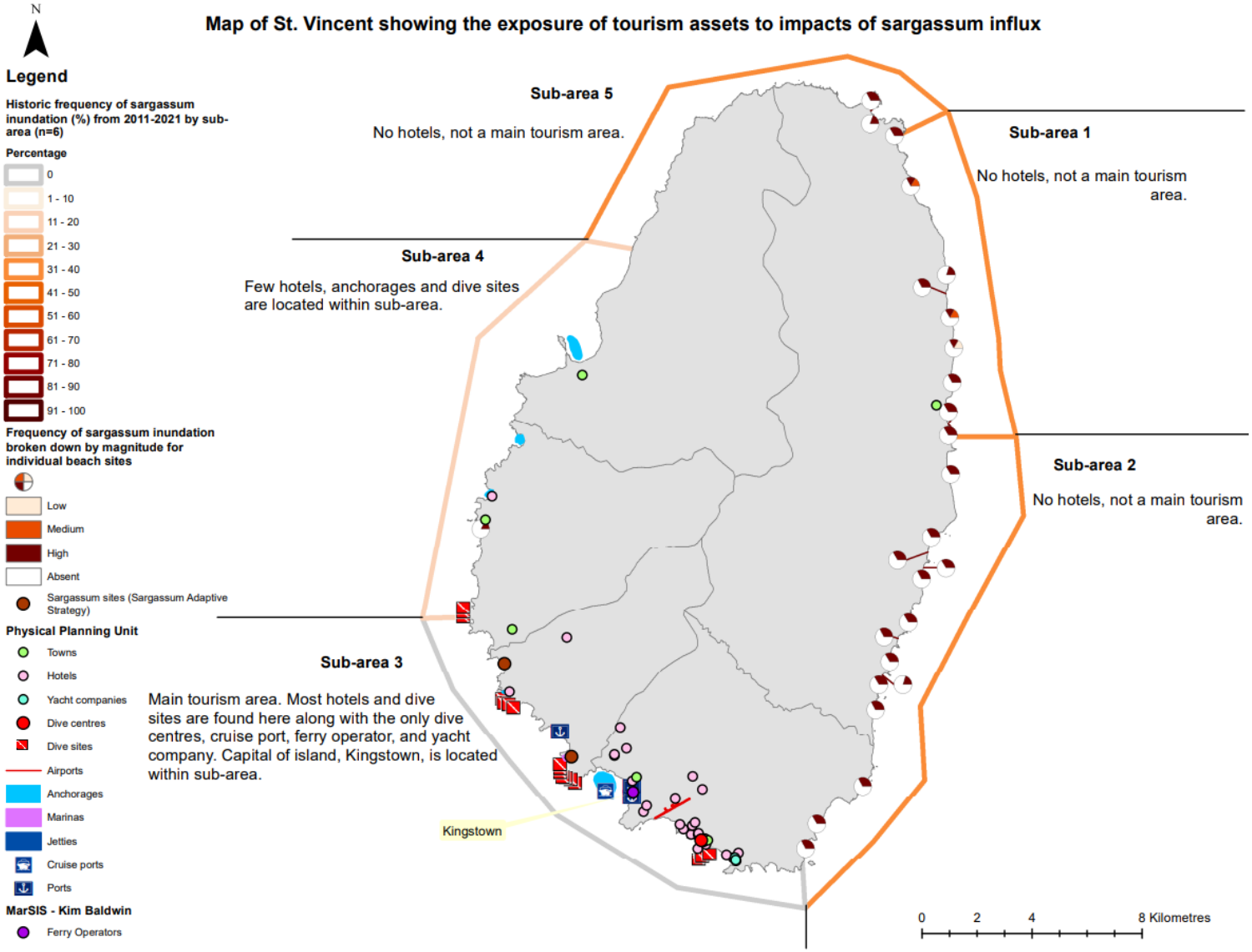

Figure 36. Map of St. Vincent showing the exposure of tourism and fisheries assets to sargassum inundation

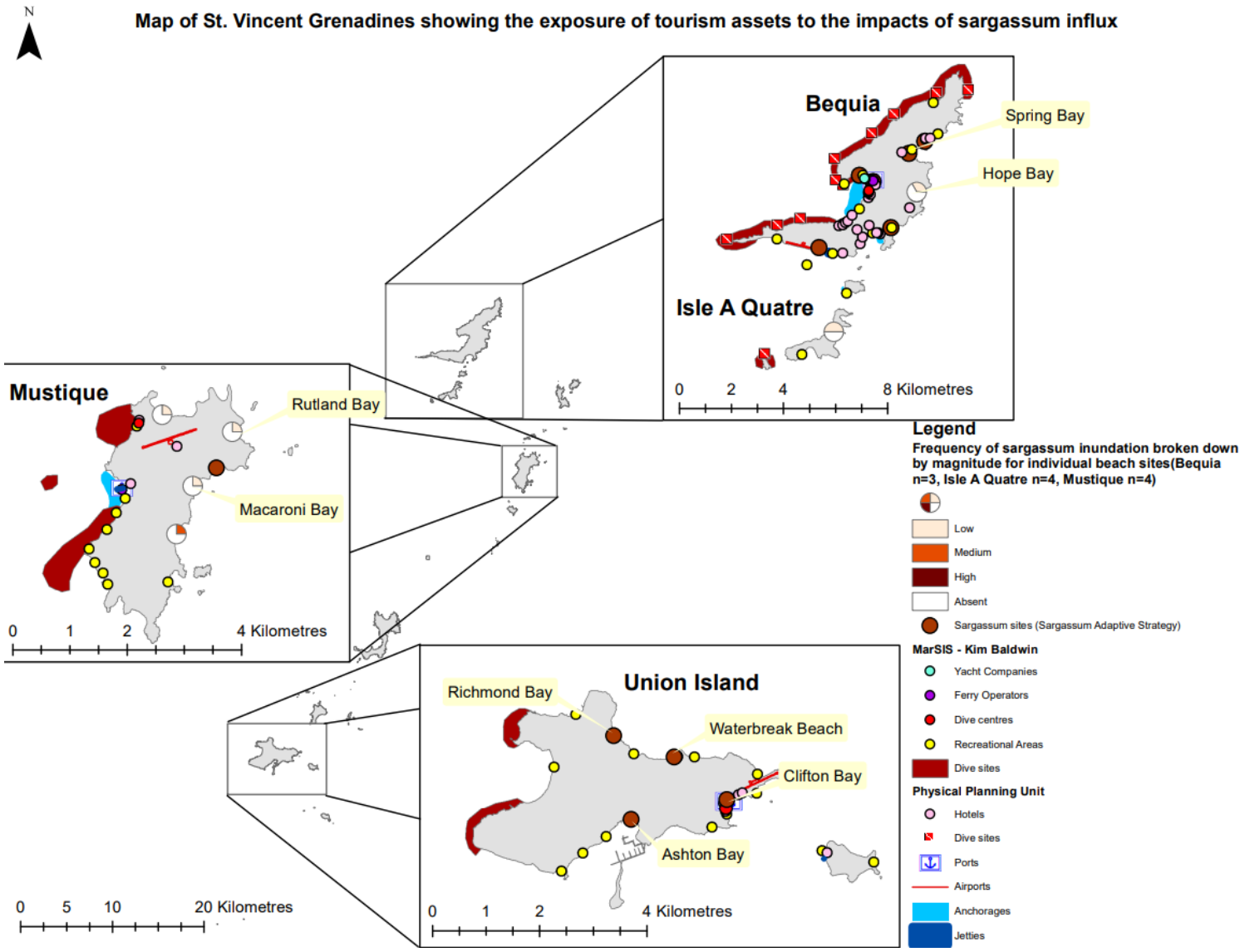

Figure 37. Map of St. Vincent Grenadines (Bequia, Isle A Quatre, Mustique, and Union Island) showing the exposure of tourism assets to sargassum inundation.

Fisheries

St. Vincent and the Grenadines has 34 officially designated fish landing sites, with 22 on the mainland and 12 on the Grenadines islands. On the mainland, most of these are located on the west, southwest and south coasts of the island with no or relatively low exposure to sargassum inundation (Figure 38). Barrouallie, Buccament Bay (SAMS site) and Lowmans Bay (SAMS site) landing sites on the west and southwest coasts are exposed to sargassum inundations. There are four landing sites on the east and northeast coasts that are exposed to high magnitude and/or frequency of sargassum inundation (Figure 38, Table 19). Of the four affected Grenadines islands, only three have fish landing sites and only two of these have fish landing sites that are affected. Bequia has six fish landing sites located all around the island and half of these are exposed to sargassum inundations based on SAMs location profiles. Meanwhile, Union Island only has two fish landing sites, and one is exposed to sargassum inundations (

Figure 39).

Table 19. Number of fish landing sites by coastal zone sub-area (CZSA) in St Vincent and the Grenadines and the names of fish landing sites exposed to sargassum inundations.

CZSA	Number of fish landing sites	Names of sites exposed
1	1	Sandy Bay
2	2	Bridgetown
		Biabou
3	6	-
4	8	Barroulie
5	2	Owia
Mustique	1	-
Bequia	6	-
Union Island	2	-

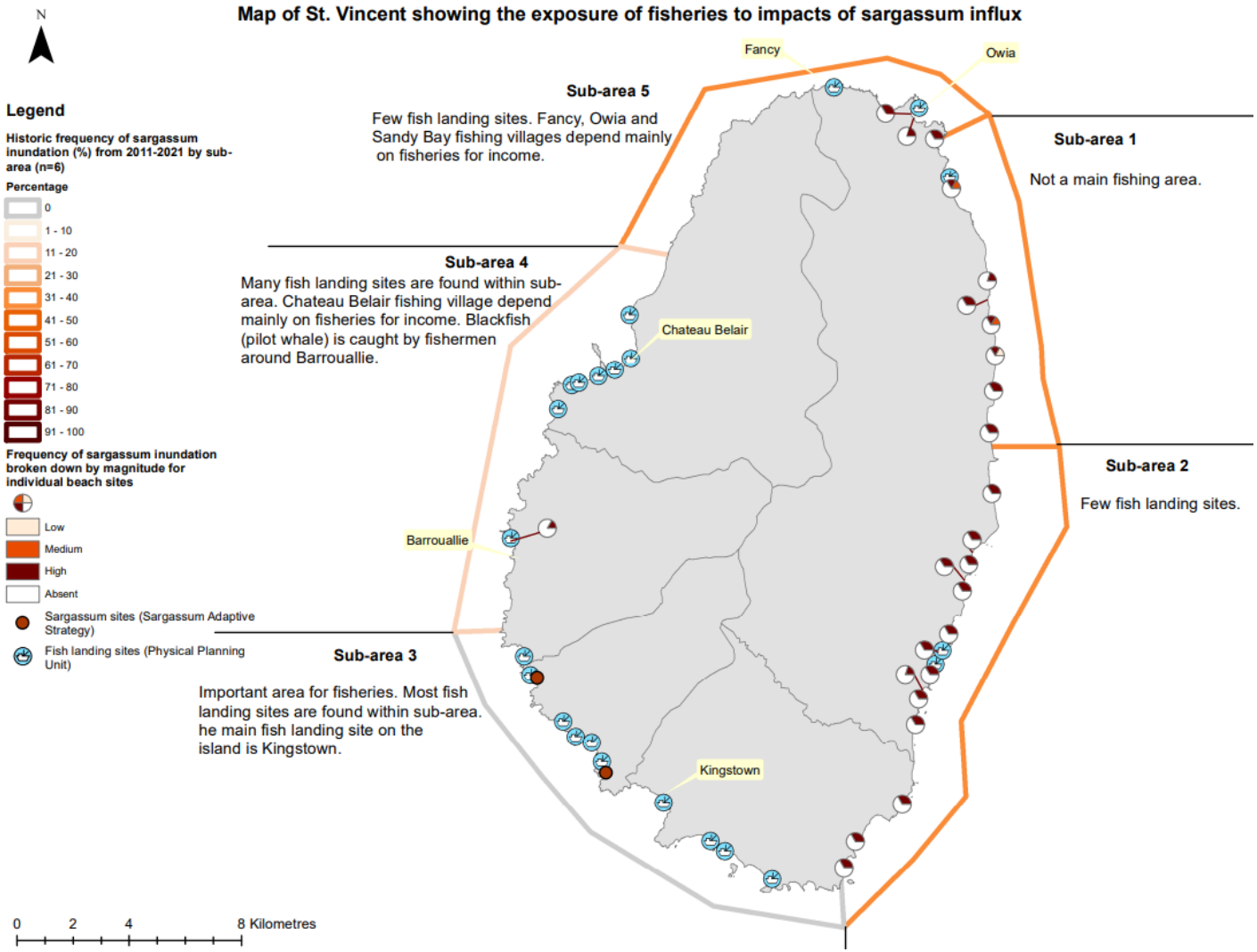

Figure 38. Map of St. Vincent showing the exposure of fisheries assets to sargassum inundation.

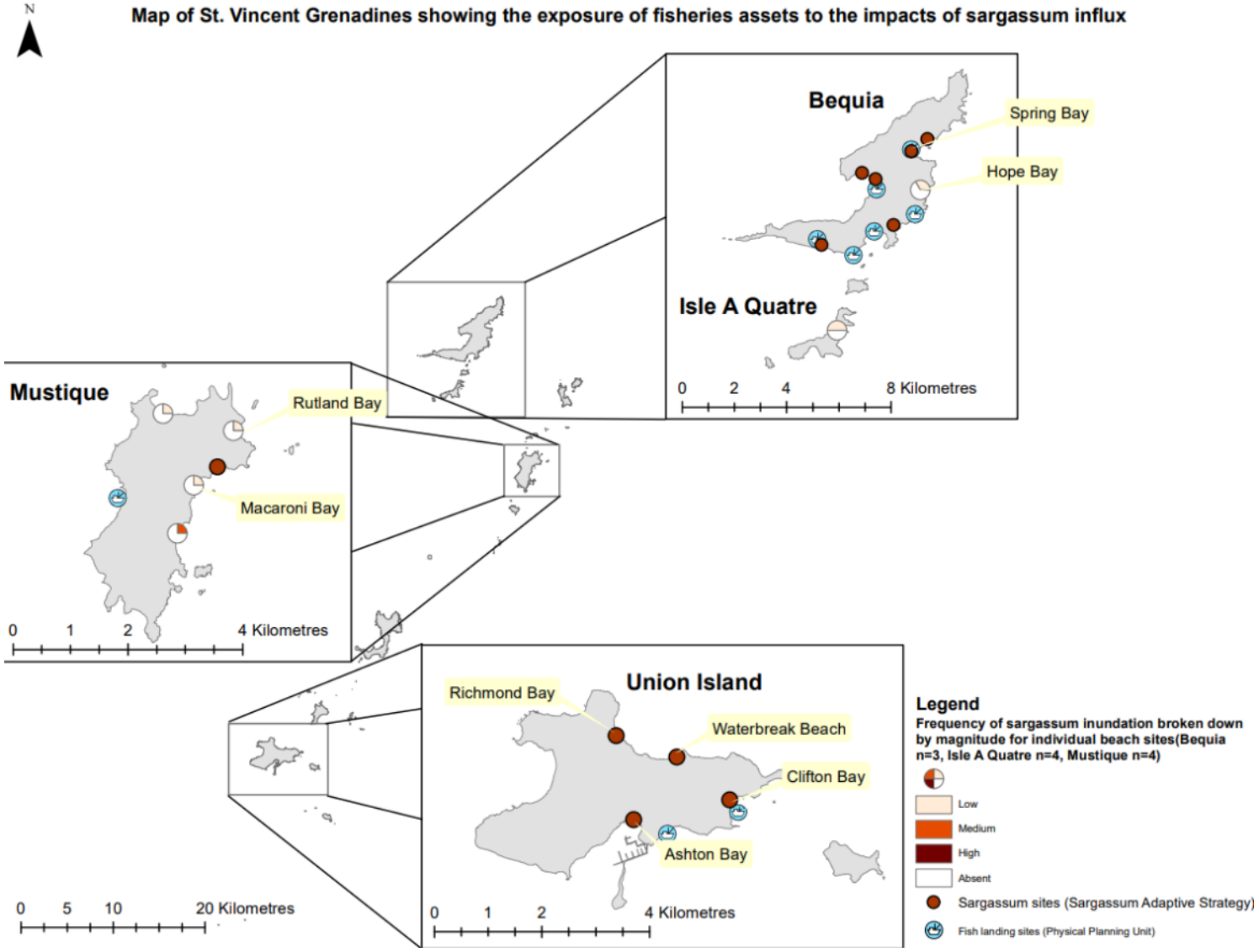

Figure 39. Map of St. Vincent Grenadines (Bequia, Isle A Quatre, Mustique, and Union Island) showing the exposure of fisheries assets to sargassum inundation.