A PARTICIPATORY GIS FOR MARINE SPATIAL PLANNING IN THE GRENADINE ISLANDS

Kimberly Baldwin
University of the West Indies
baldwin.kimberly@gmail.com

Robin Mahon
University of the West Indies
Robin.Mahon@cavehill.uwi.edu

ABSTRACT

Marine spatial planning (MSP) is a strategic way of improving decision-making and delivering an ecosystem approach to managing human activities in the marine environment. Notwithstanding the central role of human agency in these approaches, it is recognised that many times marine management has not been effective in part due to a failure to use all available sources of information and knowledge, particularly the local knowledge of the resources' users. The transboundary Grenadine Islands, which rely heavily on the marine environment for livelihoods, provide an example of a complex system where there is a high diversity of uses and all available information is needed for effective management. We illustrate how a participatory GIS approach can be applied as a sound basis for practically incorporating an ecosystem approach within marine spatial planning initiatives. Key benefits include effective data management, increased spatial understanding and the definition of critical areas across the Grenada Bank. We found the application of a PGIS approach to support spatially-based ecosystem-level analyses of the Grenada Bank to be conducted and presented in ways that could be expected to increase stakeholder understanding of information generated thus supporting marine governance.

KEYWORDS: Participatory GIS (PGIS); marine spatial planning (MSP); transboundary Grenadine Islands

1. INTRODUCTION

Successful ocean governance requires the capacity to deal with complex socio-ecological systems (Bavinck et al., 2005). Correspondingly, ecosystem-based management recognises the variety of spatial interactions within an area, including humans, rather than considering issues, species, or ecosystem services in isolation (McLeod and Leslie, 2009). It is recognised that to address these diverse and dynamic systems, management should be adaptive, based on the best available information, address issues of multiple scales, allow for inter-sectoral cooperation and promote broad stakeholder participation (Armitage et al., 2008). Despite this appreciation, the development of practical tools needed to make such an ecosystem-based management approach operational, particularly in marine and Small Island Developing State (SIDS) contexts, is just starting (Christie et al., 2005; Tallis et al., 2010).

Marine spatial planning (MSP) offers a constructive means to deal with the uncertainties associated with complex systems by focusing on the distinctive features of an individual place and tailoring management to the local circumstance through an adaptive learning cycle (Young et al.; 2008). MSP is a planning process which lays out a multi-objective, integrated vision to be developed for an area in which ecological, economic and social objectives can be simultaneously accommodated (Douvere and Ehler; 2009). MSP therefore necessitates an understanding and quantification of the spatial distribution of resources and human impacts to evaluate the trade-offs or compatibilities between the protection of the ecosystem and the services it provides (MEA, 2005). Accordingly, for effective MSP, a transparent framework that can accommodate a diversity of multi-disciplinary information is required in an accessible format that can serve to improve stakeholder understanding and involvement in decision-making (Pomeroy and Douvere, 2008; Carocci et al., 2009; Mackinson et al., 2011).

Notwithstanding the central role of human agency in the concepts of ecosystem-based management and MSP, the scope of ‘human dimension’ information included is often inadequate relative to its actual importance and complexity (St. Martin and Hall-Arber, 2008). In recent years, the use of GIS coupled with participatory approaches has emerged as a novel science known as participatory GIS (PGIS) (Chambers, 2006). A PGIS approach is both in terms of the participatory processes involved in the development of the conceptual framework as well as the construction of an appropriate, locally-relevant product (Rambaldi et al., 2006). Accordingly the process of developing of a PGIS should result in the production of information that is both understandable and accessible to stakeholders; thereby facilitating transparency, capacity-building and collaboration in decision-making (McCall, 2003). Moreover promoting the participation of stakeholders in the development of a technical representation of spatial knowledge can allow for learning and understanding of the linkages between marine resources and human communities required for ecosystem approach to management and planning (Christie et al., 2005; Chuenpagdee and Jentoft, 2009).

In this paper we demonstrate some of the ways in which a PGIS can be applied to understand and plan for marine resource management in an ecosystem-based manner, particularly in resource-limited SIDS regions such as the Caribbean. Thus, the Grenadines Marine Resource and Space-use Information System (MarSIS) was developed as part of doctoral research undertaken by the lead author to test the practical application of PGIS and examine its potential benefits for marine governance in this Caribbean sub-regional SIDS context (MarSIS, 2010; Baldwin, 2012). To illustrate its potential for MSP, a participatory geospatial framework is used to provide a baseline picture of current conditions in the transboundary Grenadine Islands.

Located in the Eastern Caribbean, the Grenadine Island chain lies atop the Grenada Bank extending some 120 km and is shared between two SIDS, Grenada and St. Vincent and the Grenadines (Figure 1). The culture and livelihoods of the Grenadine people are dependent on marine-based activities, with fishing, marine-based transport and tourism being the major sources of employment (Baldwin et al., 2006). A PGIS approach was applied to develop the Grenadines MarSIS to better understand the abundance and distribution of key marine resources and space-use patterns that are critical for planning and management of the Grenada Bank (Baldwin, 2012). The ways in which stakeholders were engaged in terms of the research approach (e.g. developing objectives, choosing methods, collecting data, determining appropriate data types and access to information) are described in detail in Baldwin et al. (2013). A description of how marine habitat maps were produced with the knowledge of stakeholders to create locally-relevant marine mapping products is described in detail in Baldwin and Oxenford (2014). The main intention of this paper is two-fold: (1) to provide a baseline of information on the extent and distribution of marine resources, associated patterns of use and the identification of threats for use in ecosystem-based management; and (2) to demonstrate to other practitioners (i.e. non-expert GIS users) the ways in which multi-knowledge information on coastal and marine resources and human activities can be brought together, analysed and used in scenario development as a starting point for MSP. Accordingly, this study does not presume to know or predetermine the management questions that would be considered important by managers and stakeholders for addressing MSP. However, without this initial demonstration of the power and utility of PGIS, neither those responsible for promoting MSP nor the other stakeholders may recognise what PGIS has to offer and may therefore fail to use its full potential.

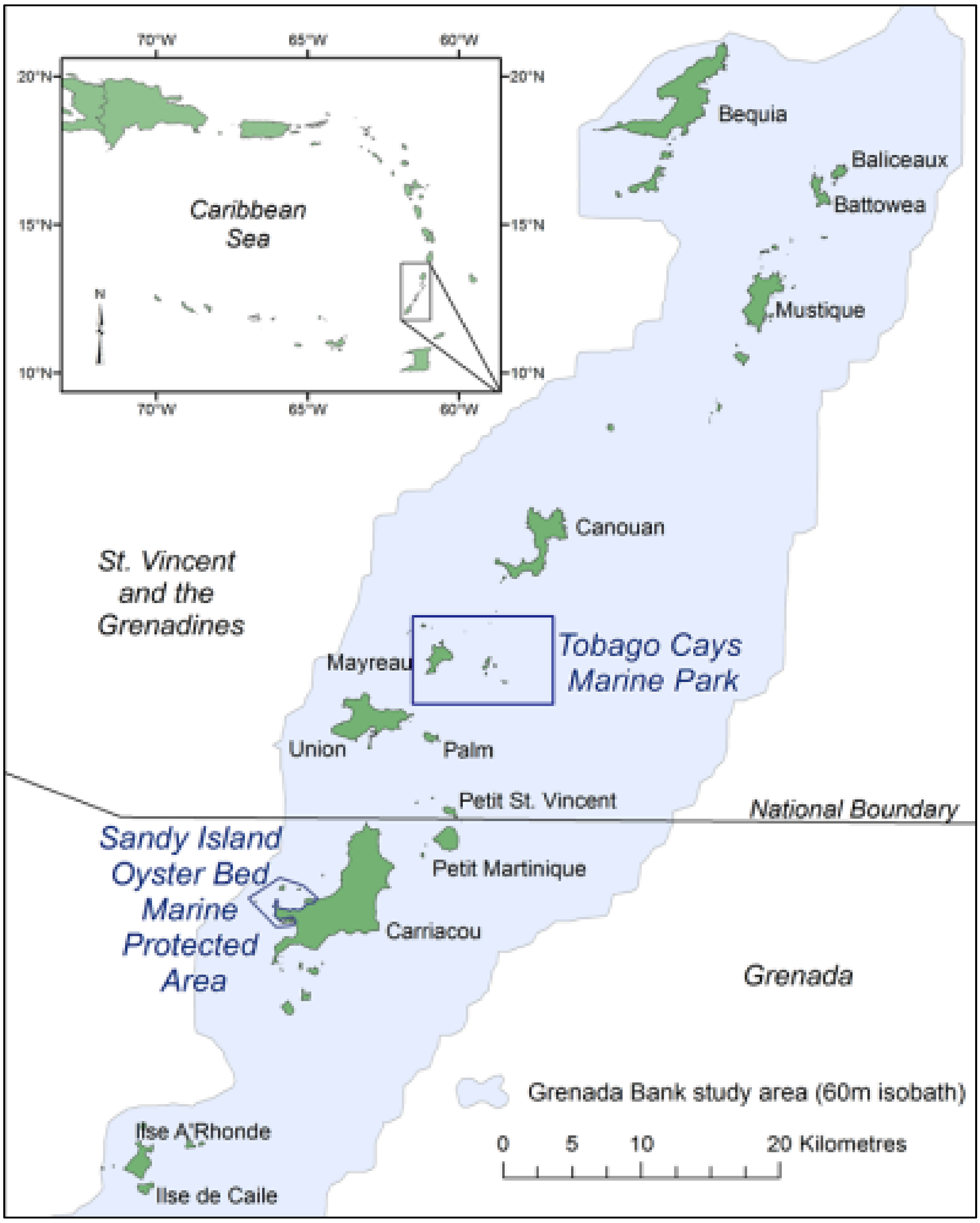

Figure 1. The geographic scope of the transboundary study area. The study area includes the Grenadine Islands and the Grenada Bank (extending to 60 m isobath). The locations of the two designated no-take marine reserves are also shown.

2. METHODS

Here we focus on aspects of the research involved in the development of the MarSIS geodatabase (namely the collection, management and processing of GIS data), as well as the use of these data to conduct practical GIS analyses and produce relevant information for MSP. The main steps in this overall procedure are described in the following subsections.

2.1 Data Collection and Definition of the Geodatabase

Ehler and Douvere (2007) identify five sources of information useful for MSP. These include: scientific literature, expert scientific opinion, government sources, local knowledge and direct field measurement. To accomplish this, a preliminary appraisal was undertaken to gather secondary information and collect primary data from all available sources (using both scientific and local knowledge systems) (Baldwin et al., 2013; Baldwin and Oxenford, 2014).

The geodatabase design was driven by the need to understand the environment and influence of human activities to support transboundary MSP for the Grenadine Islands. The MarSIS was created as a geodatabase using ArcGIS for Desktop Advanced version 10 software. All data were imported and standardised using ArcMap, ArcCatalog and ArcToolbox along with the Spatial Analyst and 3D Analyst extensions. Data were organised into feature datasets or similar 'themes' comprising physical environmental features, ecological distributions of marine resources, human activities and jurisdictional boundaries, each of which contain a number of corresponding feature classes or 'layers' categorised by name, geometry, source and geoprocessing performed.

2.2 Data Compilation, Standardisation and Processing

Much of the collected GIS data required additional processing and preparation into thematic layers. To start, the ArcToolbox 'Environment Settings' were used to allow for a standard coordinate system (e.g. WGS 84 UTM Zone 20N), spatial extent, cell size (e.g. 100 m^2) and an analyses mask of the study area (e.g. scope of Grenada Bank) to be applied to all geoprocessed data. Then, existing GIS data determined to be of use were imported, clipped to extent of the Grenada Bank study area and re-projected if necessary to a common coordinate system. Imagery, nautical charts and maps were scanned and saved as images then imported into ArcGIS. Next, the 'Georeferencing' toolbar was used to assign spatial reference information to each image.

Data on the boundaries of jurisdictional areas were either: downloaded, as in the case of the exclusive economic zone; created, by measuring a set distance from the coastline (using the Buffer tool), as in the case of territorial seas; or digitised by importing GPS coordinates, as in the case of marine protected areas. Data on infrastructure were incorporated either by digitising features from maps or remote-sensed imagery, or by importing (x, y) coordinates collected in the field using a handheld Garmin GPSmap76CSx unit. Corresponding attribute information were obtained using informational pamphlets (e.g. tourism guides, port statistics guides), phone calls, informal conversation and personal observation and referenced accordingly in the metadata.

Existing bathymetric data (FAO 2008) was enhanced by collecting sonar data (x, y, z) during field surveys and used to improve the resolution of the seafloor topography of the Grenada Bank at depths of less than 60 m (Baldwin and Oxenford, 2014). A digital elevation model (DEM) was created from the enhanced bathymetry dataset using the 3D Analyst extension (Topo to Raster tool). Next, a triangulated irregular network (TIN) three-dimensional model of the Grenada Bank seafloor was produced using the Spatial Analyst extension (Raster to TIN tool). From the TIN, bathymetry isolines (20 m and 100 m) were created (using the Contour tool).

A marine habitat map of the Grenada Bank was created in two parts as described in Baldwin and Oxenford (2014). One was a vector polygon habitat map derived using passive remote sensing and ground-truthing to model the shallow-water habitat in detail. The other map was created by using a remote video drop-camera to make direct field observations as point data (using a 3 km^2 sampling grid) which were used to interpolate (using the Spatial Analyst Expand tool) marine habitat for the deep-water area of the bank. The two marine habitat map layers were merged into a single mapping surface (using the Analysis Union tool). To prepare the data for analyses, the Grenada Bank vector habitat model was converted to a raster surface (using the Polygon to Raster Conversion tool).

Participatory research methods (e.g. socio-economic surveys, mapping exercises, marine field surveys) were used to solicit and incorporate spatially-based local knowledge within the geodatabase and fill information gaps on human use (Baldwin et al., 2013; Baldwin and Oxenford, 2014). Spatial information derived from mapping exercises was scanned and imported into GIS. Features of interest were digitised. Corresponding attributes collected as part of socio-economic assessment (Baldwin et al., 2013) were first entered into Excel as tables and subsequently connected (using a table join) to relevant spatial data from the mapping exercises. An additional 12 fishing-related raster mapping surfaces were interpolated (i.e. Inverse Distance Weighting) from marine field survey variables designed to collect fishers' evaluation of fishing suitability (e.g. species, gear type and ground quality) information (Baldwin and Oxenford, 2014).

Next the spatial extent of marine and coastal activities was mapped. As little was known about the geographic extent of impact beyond the location of the activity, buffers were applied to point and line vector feature classes to represent all data as polygon feature classes (as specified in Table 1). Polygon feature classes were then converted to raster surfaces (using the Polygon to Raster tool). Given that all activities do not affect the marine environment equally, a measure of the impact at the location of the occurrence can be incorporated to each feature using a weighted ranking scale. As ranking impacts are known to be contentious (Ban et al., 2010) and the analyses in this study are for demonstration purposes; weighting was not applied. Instead all features were determined to have an equal impact established by a simple measure of presence or absence. To accomplish this, all rasters were further processed using Spatial Analyst (Is Null and CON tools) to create raster surfaces in which a value of '0' indicated absence and '1' indicated presence of a variable within the study area.

2.3 eGIS Applications for MSP

The application of GIS to integrate, display, query and analyse information is widely recognised as valuable for ecosystem-based decision-support and MSP (Ehler and Douvere, 2009; FAO, 2013). The basic requirements for MSP include an inventory of important ecological areas, current human activity and the identification of conflict or threat among and between uses and the environment (Douvere and Ehler, 2009; Tallis et al., 2010). To illustrate, the MarSIS is used to demonstrate practical GIS applications that serve to define and analyse these basic requirements for the Grenada Bank.

The following analyses are presented:

- Mapping of marine resources and associated human activity
- Quantification of coastal and marine resources
- Geo-visualisation of fishing patterns
- Identification of priority conservation areas
- Spatial evaluation of management scenarios and trade-offs

3. RESULTS AND DISCUSSION

3.1 Data Collection and Definition of the Geodatabase

Collecting data, defining the geodatabase structure and populating the geodatabase was an iterative process initially taking about 18 months, but continuing throughout the remainder of the research (additional 36 months). A total of 16 satellite imagery datasets, 4 nautical charts and 7 topographic maps; 36 technical reports containing maps or atlases, and more than 200 GIS files were collected and reviewed for use (Baldwin, 2012). The main challenge in the review of existing data was an almost total absence of metadata. Much time was therefore spent communicating with the data creators when possible, in order to determine the accuracy, scale and methods that were applied to each dataset. Ultimately, none of the existing GIS datasets were useable without some form of remedial geoprocessing (Table 1). Besides the imagery and mapping datasets, only six pre-existing GIS files were found to be relevant for inclusion in the MarSIS.

3.2 Data Compilation, Standardisation and Processing

The collection and conversion of data from disparate sources, scales and participatory research methods (e.g. interviews, mapping exercises, field surveys) constituted the main challenge during this phase. The 'Environment Settings' allowed for the production of a consistent spatial extent and cell size to be applied to all geoprocessed data. Ultimately the MarSIS geodatabase consisted of 11 feature datasets, comprising 81 feature classes (e.g. 46 vector, 28 raster and 1 annotation) (Table 1), of which 63% was derived in part, based on the use of local knowledge sources (Baldwin et al., 2013; Baldwin and Oxenford, 2014).

3.3 GIS Applications for MSP

3.3.1 Mapping of Marine Resources and Associated Human Activity

One benefit of GIS is that it provides users with the ability to easily create maps to provide a better understanding of the interactions occurring within a particular environment. There are currently two marine protected areas (MPAs) located within the Grenada Bank study area: the Tobago Cays Marine Park (TCMP) under the jurisdiction of St. Vincent and the Grenadines; and Sandy Island Oyster Bed Marine Protected Area (SIOBMPA) under the jurisdiction of Grenada (Figure 1). Maps of the coastal marine resources and human activities' occurring in TCMP were created to allow for increased understanding of the amount of conservation afforded and corresponding livelihoods generated by the protected area (Figure 2).

The TCMP habitat and resource map (Figure 2a), shows the large reef system within the park boundary. All marine and coastal habitats are represented, including a salt pond and four small stands of mangrove. There are eight sea turtle nesting beaches, eight fish nursery areas and three cays identified as seabird nesting areas. The TCMP contains the inhabited island of Mayreau, on which the largest amount of human activity within the park is seen to occur (Figure 2b). This includes: recreation (i.e. 11 coastal areas used by the community); fishing (i.e. two fish landing sites, seven bays where baitfish are harvested and ten areas where whelks are collected); and transportation (i.e. one seaport, two water-taxi kiosks and a shipping lane). Several tourism-related activities are prevalent in the TCMP (i.e. seven anchorages, two hotels, three vending sites, five major dive/snorkel sites and two ship wrecks utilised as dive sites). Even without any spatial analyses, these maps illustrate the diversity of resources and uses occurring within the boundaries of the TCMP.

Table 1. The geodatabase structure of the MarSIS listed by feature dataset, feature class, data model, source and geoprocessing applied (*Adapted from Baldwin 2012*).

Feature dataset	**Feature class**	**Data model**	**Source**	**Geoprocessing**
Bathymetry	Grenada Bank contour (200 m)	Line	FAO	Spatial Analyst (Contour)
	Grenada Bank contour (10 m)	Line		
	Grenada Bank (50 m)	DEM	FAO & field survey	Analysis (Union); 3D Analyst (Topo to Raster)
	Grenada Bank (50 m)	TIN	Grenada Bank DEM	3D Analyst (Raster to TIN)
Infrastructure	Roads	Line	The Nature Conservancy	None
	Coastlines	Line	Imagery	Digitised
	Hotels	Point	Imagery	Digitised; Analysis (500 m Buffer)
	Airports			
	Seaports			
Marine habitat	Shallow water habitat	Polygon	Remote sensing & field survey	Digitised
	Deep water habitat	Raster	Field survey	Spatial Analyst (IDW)
	Grenada Bank habitat	Polygon	Shallow & deep habitat	Analysis (Union)
	Geomorphology	Polygon	Coral Reef Millennium Data	Analysis (Clip)
	Shoreline type	Polygon	The Nature Conservancy	Analysis (Union)
Resources	Seabird nesting areas	Polygon	West Indian Seabird Atlas (EPIC)	Digisited from survey data
	Mariculture (seamoss)	Point	Mapping exercises	Digitised; Analysis (200 m Buffer)
	Sea turtle nesting			
	Shipwrecks			
	Baitfish bays	Polygon	Mapping exercises	Digitised
	Nursery areas			
	Oyster beds			
	Whelks	Line	Mapping exercises	Digitised; Analysis (100 m Buffer)
Resource users	Day-tour operators	Point	Imagery; socio-economic surveys	Digitised; Join related tables
	Water-taxi operators			
	Ferry operators			
	Dive shops			
	Fishers			
	Ships			
	Yacht companies			
Space-uses	Fish landing sites	Point	Mapping exercises	Digitised; Analysis (200 m Buffer)
	Recreation (community)			
	Vending			
	Shipbuilding			
	Anchorages	Polygon	Mapping exercises	Digitised from map
	Dive sites			
	Shipping lanes	Line	Mapping exercises	Digitised; Analysis (500 m Buffer)
Fishery	Conch (yes/no)	Raster	Field survey	Spatial Analyst (IDW)
	Lobster (yes/no)			
	Fish (yes/no)			
	Presumed fishing quality (1-5)			
	Fishing preference (yes/no)			
	Weighted fishery overlay (density)		Modeled (fishery)	Spatial Analyst (Weighted Overlay)
Fishing gear	Tank (yes/no)	Raster	Field survey	Spatial Analyst (IDW)
	Spear gun (yes/no)			
	Fish trap (yes/no)			
	Net (yes/no)			
	Line (yes/no)			
	Weighted gear overlay (density)		Modeled (gear)	Spatial Analyst (Weighted Overlay)
Threats	Landfills	Point	Mapping exercises	Digitised; Analysis (200 m Buffer)
	Illegal dumping			
	Artificial structures	Polygon	Mapping exercises	Digitised
	Sand-mining			
	Dredging			
	Quarries			
	Mangrove cutting			
	Desalination outfalls	Line	Mapping exercises	Digitised; Analysis (200 m Buffer)
Other	Marine protected areas	Polygon	GPS coordinates	Add X,Y points; Digitised from points
	Exclusive economic zone		VLIZ Maritime Boundaries	Analysis (Clip)
	Territorial seas		Modeled (coastline)	Analysis (3 km Buffer)
	Scope Grenada Bank		Modeled (bathymetry)	Analysis (Selection 60 m contour)
	Local name - coastal features	Annotation	Mapping exercises	Digitised
Imagery / Basemaps	Digital Globe (1 m)	Image	Purchased	None
	IKONOS (4 m)		FAO	
	LandSat (40 m)		USGS	
	Aerial photos		St. Vincent Government	Georeferenced
	Nautical charts		3 Imary and 1 US Navy	
	Topographic maps (1:25,000)		6 Lands and Survey Dept.	

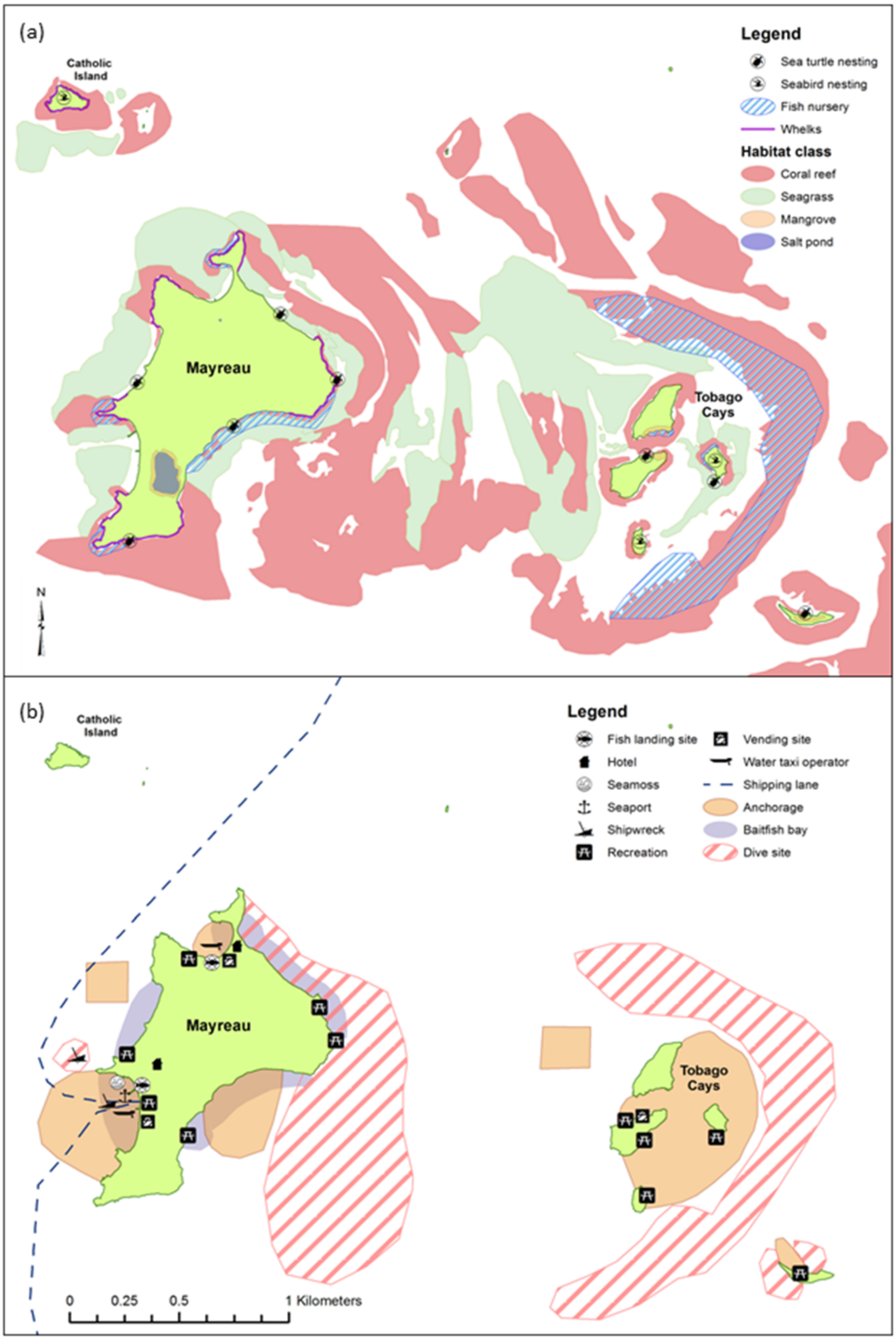

Figure 2. Maps showing the location of: (a) important marine habitat and resources; and (b) the location of human activities that occur within the Tobago Cays Marine Park, St. Vincent and the Grenadines.

3.3.2 Quantification of Coastal and Marine Resources

Understanding the amount and distribution of ecosystems, structurally and functionally, is essential for MSP initiatives (Ehler and Douvere, 2009). Geoprocessing tools can allow for the integration of data layers to help explore patterns that occur between and among habitats and resources as well as the relationships between the resource users. For example, overlay analyses can be applied to calculate summary statistics (e.g. count, sum, mean, minimum, maximum) between spatially-based features. The GIS interface is applied to quantify the existing amount of the various coastal and marine habitat, fishing grounds and presumed fishing quality found within the Grenada Bank study area as well as by national jurisdictional area (Table 2). The Grenada Bank study area consists of 190,985 hectares; of which 71% belongs to the country of St. Vincent and the Grenadines, and the remainder to Grenada. Reef and reef-related (mixed live bottom) habitats comprise the largest amount of habitat (79%) found on the Grenada Bank. St. Vincent and the Grenadines was found to have proportionally more of each habitat type, except for mangrove of which 60% is located on the Grenada portion of the study area. With regard to fisheries, lobster and reef fish fishing grounds are found to be more widely distributed across the bank (74% and 83% respectively) than conch fishing grounds (25%) (Table 2). Lobster and reef fish fishing grounds tend to be located in reef and reef-related (mixed live bottom) habitats (91% and 89% respectively); whereas conch grounds are split among mixed live bottom (45%), reef (23%) and hard bottom (20%) habitats. Three quarters of the Grenada Bank is identified to be of high quality (defined as very good or good) fishing habitat. Likewise the areas that fishers indicate to be of very good (98%) and good (80%) fishing quality consist primarily of reef and reef-related (mixed live bottom) habitats. Despite the presence of 142,252 hectares of identified high quality fishing habitat, it is of interest that fishers prefer only 10% (20,027 hectares) of the Grenada Bank for fishing.

GIS can be used as a tool to monitor a country’s progress towards achieving marine conservation targets. To demonstrate, overlay analyses of the jurisdictional boundary of each MPA with coastal and marine habitat has allowed for: (1) an inventory of habitat located within each conservation area; (2) an assessment of the amount of each habitat type afforded protection as compared to the total amount occurring on the Grenada Bank; and (3) an evaluation of each country’s progress towards achieving their Convention on Biological Diversity ‘Caribbean Challenge Initiative’ marine conservation targets of 10% protection by 2012 and 20% by 2020 (CCI, 2013; Table 4). The TCMP consists of 6,201 hectares and is 7 times larger than SIOBMPA which comprises 888 hectares. Likewise within the Grenada Bank study area, the TCMP protects 4.6% of St. Vincent and the Grenadines marine area; whereas the SIOBMPA only protects 1.6% of Grenada’s marine area (Table 3). However, in terms of protecting representative reef ecosystem habitat (e.g. mangrove, reef and seagrass), SIOMPA may be more effective than TCMP. Within the boundaries of SIOBMPA, 7% (66 ha) is mangrove, 26% (227 ha) is seagrass and 19% (166 ha) is coral reef (Figure 3a). In the TCMP less than one percent (4 ha) is mangrove habitat, 6% (365 ha) is seagrass and 22% (1,370 ha) is coral reef habitat (Figure 3b). These types of straightforward analyses show how GIS can easily and quickly be used to access and summarise spatial data into information for evaluating the effectiveness of MSP initiatives.

Table 2. Table of marine habitats found in the study area; summarised as total area (hectares) and percent (%) total of the Grenada Bank broken down by national jurisdiction, fishery species, fishing gear suitability and presumed fishing quality. (GB = Grenada Bank). *(Adapted from Baldwin 2012).*

Variable			Reef	Mixed live bottom	Hard bottom	Sand	Seagrass	Mangrove	Salt pond /swamp	**Area (ha) & % GB**
Grenada Bank	Study area	Area (ha)	73,383	77,800	22,685	13,974	2,932	161	50	**190,985**
		% total	38	41	12	7	2	0	0	**100**
	St. Vincent & the Grenadines	Area (ha)	42,179	67,534	13,575	10,977	1,420	64	33	**135,782**
		% total	57	87	60	79	48	40	66	**71**
	Grenada	Area (ha)	31,204	10,266	9,110	2,997	1,512	97	17	**55,203**
		% total	43	13	40	21	52	60	34	**29**
Fishery Species	Conch	Area (ha)	11,006	21,543	9,420	4,903	1,274	NA	NA	**48,146**
		% total	23	45	20	10	3	NA	NA	**25**
	Lobster	Area (ha)	65,501	63,752	7,581	3,714	909	NA	NA	**141,457**
		% total	46	45	5	3	1	NA	NA	**74**
	Fish	Area (ha)	68,220	73,149	11,588	4,647	1,414	NA	NA	**159,018**
		% total	43	46	7	3	1	NA	NA	**83**
Fishing Gear suitability	Fish trap	Area (ha)	58,239	53,611	9,125	2,815	774	NA	NA	**124,564**
		% total	47	43	7	2	1	NA	NA	**65**
	Line	Area (ha)	64,532	68,530	8,969	3,610	865	NA	NA	**146,506**
		% total	44	47	6	2	1	NA	NA	**77**
	SCUBA tank	Area (ha)	43,007	62,176	13,816	6,040	692	NA	NA	**125,731**
		% total	34	49	11	5	1	NA	NA	**66**
	Seine net	Area (ha)	52,475	31,187	8,317	1,635	764	NA	NA	**94,378**
		% total	56	33	9	2	1	NA	NA	**49**
	Spear gun	Area (ha)	38,814	59,442	7,909	3,851	1,080	NA	NA	**111,096**
		% total	35	54	7	3	1	NA	NA	**58**
Presumed Fishing Quality	Very good	Area (ha)	36,452	22,923	744	456	105	NA	NA	**60,680**
		% total	60	38	1	1	0	NA	NA	**32**
	Good	Area (ha)	26,429	39,310	11,281	3,821	731	NA	NA	**81,572**
		% total	32	48	14	5	1	NA	NA	**43**
	OK	Area (ha)	8,417	12,854	8,087	4,870	1,372	NA	NA	**35,600**
		% total	24	36	23	14	4	NA	NA	**19**
	Poor	Area (ha)	2,086	2,713	2,574	4,828	725	NA	NA	**12,926**
		% total	16	21	20	37	6	NA	NA	**7**
	Preferred fishing grounds	Area (ha)	7,930	5,820	2,491	2,513	1,273	NA	NA	**20,027**
		% total	40	29	12	13	6	NA	NA	**10**

Table 3. Area (in hectares) of each habitat type contained within the Tobago Cays Marine Park (TCMP) and Sandy Island Oyster Bed Marine Protected Area (SIOBMPA), also represented as a percentage of overall habitat protection for each respective country. (SVG – St. Vincent and the Grenadines; GND – Grenada). *(Adapted from Baldwin 2012).*

	TCMP		SIOBMPA	
Class	Area (ha)	Percent SVG total	Area (ha)	Percent GND total
Coral reef	1,370	3.2	166	0.5
Mangrove	4	6.0	66	68.0
Mixed live bottom	1,585	< 0.1	223	2.2
Hard bottom	2,137	15.7	168	1.8
Salt pond	5	16.2	1	8.5
Sand	734	6.7	37	1.2
Seagrass	365	25.7	227	15.0
Total	6,201	4.6	888	1.6

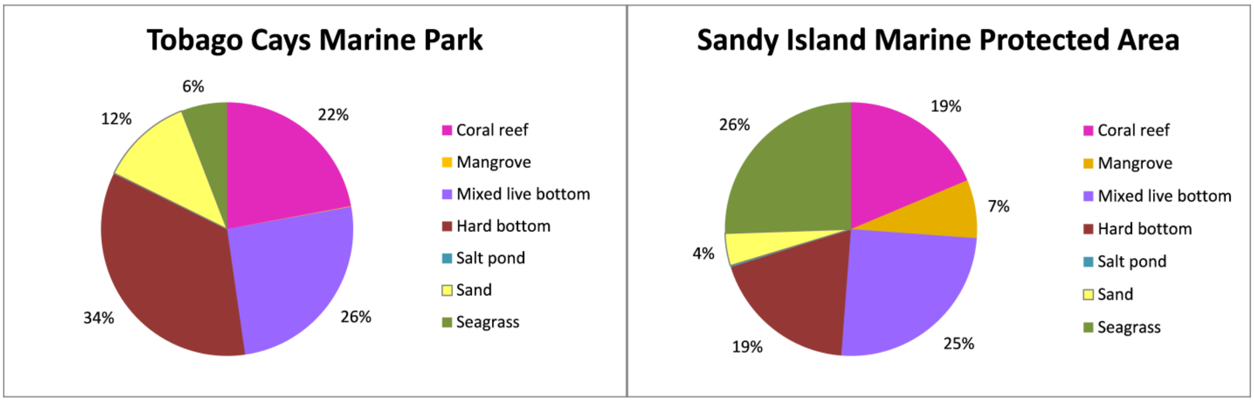

Figure 3. Charts showing the proportion (percentage) of each habitat type contained within the: (a) Tobago Cays Marine Park (TCMP); and (b) Sandy Island Oyster Bed Marine Protected Area (SIOBMPA).

3.3.3 Geo-visualisation of Fishing Patterns

An important aspect of ecosystem-based management is to understand not only the location of resources but the influence that humans are having on them. GIS can be applied to explore the interactions among variables, evaluate trade-offs and prioritise management objectives. For instance, visual examination of the location of preferred fishing grounds reveals spatial patterns that are not obvious from summary statistics (Table 2). Overlaying the location of high quality (i.e. very good and good) fishing grounds and the location of preferred fishing areas provides insight on human-environment interactions and patterns of space-use on the Grenada Bank (Figure 4). It is apparent that fishers prefer to fish close to shore in shallower water which means that a large amount of high quality fishing grounds is not exploited on the Grenada Bank. This pattern is probably due to several factors: economic (cost of fuel and time of travel), physical (limitation of depth and current relating to the deployment of gear and diving), and perhaps safety. This finding is of particular importance to MSP in that it indicates a spatial preference by fishers despite the large occurrence of high quality fishing grounds. This finding may have several important implications for MSP. To start, there may be a certain degree of 'natural or environmental' protection of habitats and resources taking place by virtue of the limitations of fishing methods and vessels that are currently in use. Those who may seek to develop or modernise the fishing industry of the Grenadines should be conscious of how their initiatives may affect this current situation. Additionally, this information may be of use in the determination of feasible conservation or 'no-take' fishing areas by aiding the selection of areas which are not high priority fishing banks. These types of analyses can contribute to MSP through identification of potential conservation zones in areas with low use by fishers. This approach may meet with little resistance from or have little impact upon fishers thereby assisting management acceptance and compliance.

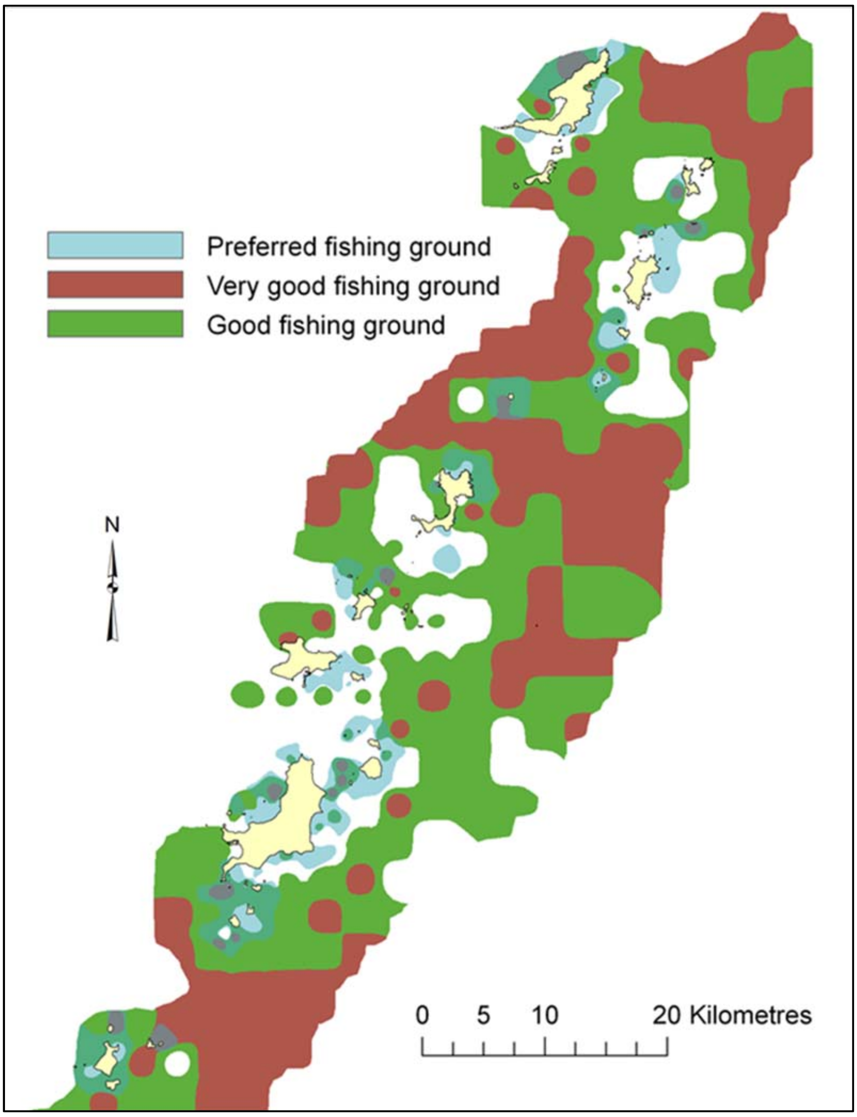

Figure 4. A map of the spatial distribution of preferred fishing areas and the location of high quality (very good and good) fishing grounds. (Adapted from Baldwin 2012).

3.3.4 Identification of Priority Conservation Areas

Although basic GIS functions such as summarising and visualising information are valuable, the development of a marine space-use plan typically includes advanced spatial queries (Agardy, 2010; Agostini et al., 2010; Maelfait and Belpaeme, 2010). Spatial queries based on the proximity of features can be valuable for marine conservation prioritisation (FAO, 2013). For example, a well-connected reef ecosystem is known to include adjacent areas of mangrove, seagrass and reef habitat. The identification of areas where these habitats occur in such a way as to represent a reef ecosystem can be an important step in identifying critical areas for conservation. To demonstrate, a spatial query was applied to identify the location of all mangroves found within the Grenada Bank study area. Next, a locational query was used to detect the existence of seagrass habitat within a distance of 50 m of the selected mangroves. Finally, a further query was used to identify those mangrove/seagrass combination areas where coral reef habitat was located within 100 m. A total of 13 adjacent coastal mangroves, seagrass beds and coral reef habitats (areas considered to be representative reef ecosystems) are found on the Grenada Bank (Figure 5). These areas are considered to be important for reef and fisheries resilience. They may also be important for evaluating the location of existing conservation efforts or for selecting additional areas for management protection.

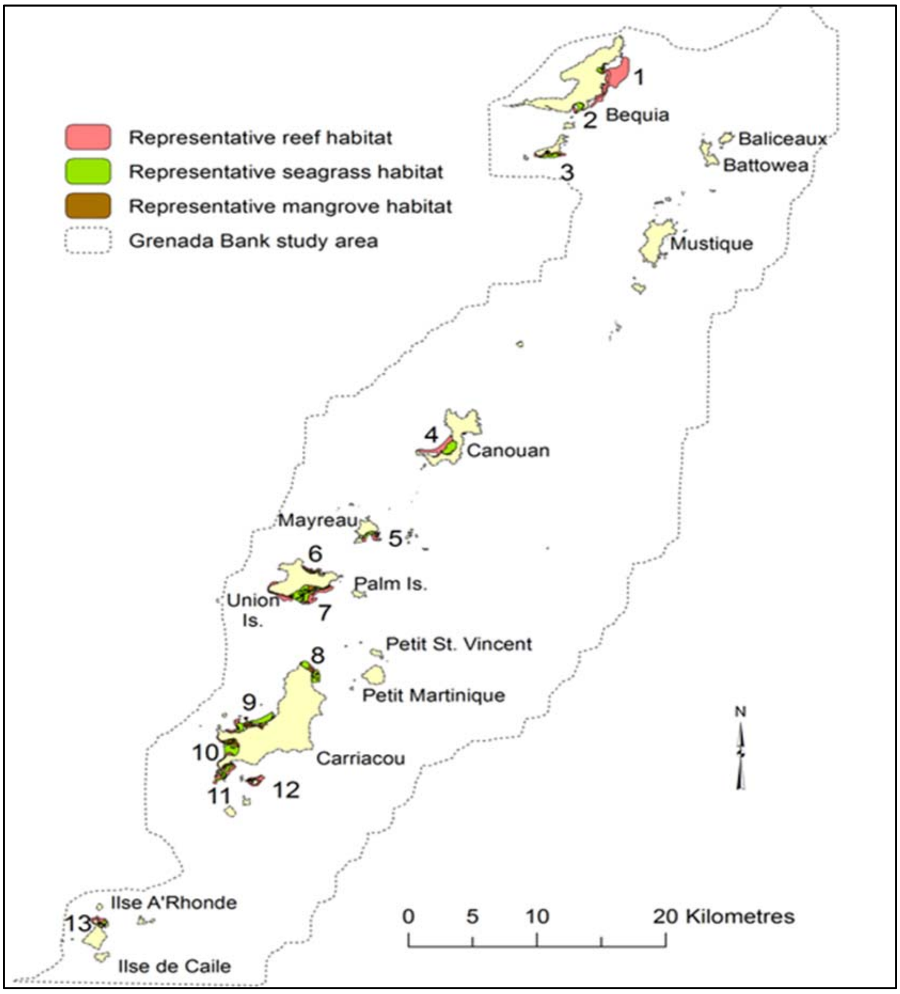

Figure 5. A map showing the location of representative reef ecosystems identified for the Grenada Bank.

(Adapted from Baldwin 2012).

3.3.5 Spatial Evaluation of Management Scenarios and Trade-offs

Once ecosystem conservation priorities have been identified, their potential impact on livelihoods and management feasibility should be assessed (Agardy, 2010; CBD, 2012). For example, the location of reef ecosystems and areas of identified threat could be explored to prioritise conservation efforts on areas with higher environmental integrity. In terms of social acceptance of management, consideration should be given to the human activities which occur in the area so as to assess the possible displacement of resource users and weigh the potential impact on livelihoods. Finally, the location of towns and supporting infrastructure can be considered so that management feasibility can be determined. The development of MSP scenarios and the evaluation of socio-economic trade-offs such as these are critical to determining effective, socially-acceptable management measures (Agardy, 2010; Agostini et al., 2010).

Identifying multiple-use areas, where human uses are co-occurring, and their proximity to critical resources can be important to prioritise management efforts. For example, overlaying areas of high conservation priority with areas of identified threat can highlight potential space-use conflicts which can ultimately undermine conservation effectiveness. Likewise, overlaying areas of high human activity with conservation priority may be of use in weighing various scenarios and assist the identification of the most cost-effective options for conservation or the management of high use areas. To demonstrate, multiple-use areas (e.g. where resources of concern may be abundant, human activity impacts may be high, and/or there may be conflicts amongst uses) were identified through the development of ‘cumulative impact’ surfaces for the Grenada Bank.

Three cumulative impact mapping surfaces were created to pinpoint areas of importance for conservation, human use and threat in the Grenadine Islands based on the feature classes listed in Table 4. To produce a cumulative impact surface, each resource or space-use feature layer was mapped onto a gridded raster surface. Where resources or activities of interest overlap in the same location (or grid cell), the values were added (using the SUM overlay of the Cell Statistics geoprocessing tools). Each resulting cumulative impact mapping surface represents the raster cells where the features (i.e. resources or activities) of interest co-occur indicating areas of importance. These surfaces were then compared to underscore areas of overlapping or conflicting use and develop scenarios to assist in the evaluation of trade-offs required for MSP decision-making. It should be recognised that due to data limitations, these results are biased towards the near-shore marine and coastal environment. Nonetheless, this is where most human activity takes place and valuable information for MSP can be generated.

Table 4. The feature classes used to create each of the three cumulative impact surfaces; one each for conservation, human use and threat.

Conservation	Human use	Threat
Coral reefs	Anchorages	Artificial structures
Mangroves	Mariculture	Desalinisation outfalls
Nursery grounds	Baitfish bays	Dredging
Oyster beds	Dive sites	Illegal dumping
Seabird nesting	Landing sites	Landfills
Sea turtle nesting	Recreation	Mangrove cutting
Seagrass beds	Seaports	Sand mining
Whelks	Ship building	
	Ship wrecks	
	Shipping lanes	
	Vending sites	

A closer examination of these surfaces for the island of Carriacou reveals some interesting patterns (Figure 6). The composite conservation map (Figure 6a) highlights priority areas for conservation; the composite human activity map Figure 6b shows areas important for marine-based livelihood (i.e. social well-being); and the composite map of threat (Figure 6c) shows areas at highest risk of degradation. All three cumulative impact surfaces show a multiple-use area located in Tyrell Bay adjacent to the village of Harvey Vale. The Careenage mangrove (a part of the SIOBMPA) is identified as being an area of high (five overlapping features) conservation priority including a representative reef ecosystem (Figure 5). Tyrell Bay is also a major seaport, heavily used by tourists as a preferred yachting anchorage and the site of several types of human activities important for the surrounding communities (i.e. fish landing site, baitfish bay, ship building site vending site) (Figure 6b). Several threats are identified, including mangrove cutting, illegal dumping, artificial coastal structures and dredging for the construction of a marina in the area (Figure 6c). These types of findings can be used in MSP, especially as the human uses and threats are near the boundary of the newly established SIOBMPA (Figure 1). The high amount of threat and human activity identified in this analysis may not be consistent with the conservation action and may ultimately weaken the effectiveness of this MPA. This information could be used to develop management priorities to address the impacts within the area. Ultimately these types of GIS analyses can be used to develop scenarios and to understand the extent and distribution of existing resources and their relationship to livelihoods that facilitate the evaluation of trade-offs between uses and management action.

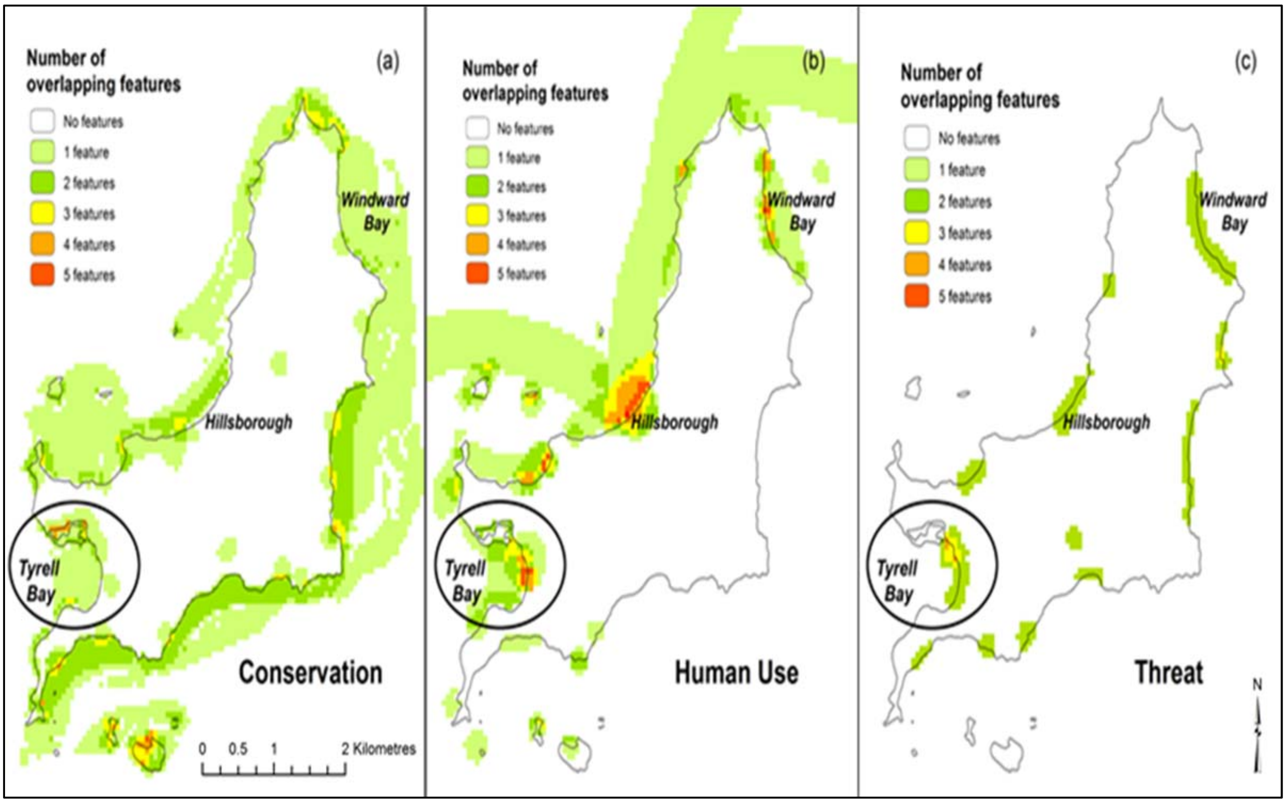

Figure 6. Cumulative impact surfaces for: (a) conservation, (b) human use and (c) threat highlighting an area of space-use overlap for the island of Carriacou, Grenada. (Adapted from Baldwin 2012).

4. CONCLUSION

The usefulness of integrating interdisciplinary, multi-knowledge information for MSP is well documented (De Young and Charles, 2008; De Freitas and Tagliani, 2009; Dalton et al., 2010; Tallis et al., 2010). However, the actual framework and practical methodologies for achieving holistic ecosystem-based information is lacking (Douvere and Elher, 2009; FAO, 2013). We found a PGIS approach useful for collecting, integrating and understanding multi-knowledge interdisciplinary information. It presented a variety of valuable opportunities for realising MSP on the Grenada Bank. Aside from the fact that the majority (63%) of information in the geodatabase was derived from local knowledge (Baldwin et al., 2013), in particular information on human activities, we demonstrate a number of practical GIS analyses applied to produce relevant ecosystem-based information. These types of analyses can be useful to determine the spatial allocation of the sea in a way that maximises societal benefits and mitigates possible conflicts. Additionally, the application of a PGIS approach (in terms of both information integration and visualisation) proved beneficial in that it allowed for spatially-based ecosystem-level analyses of the Grenada Bank to be conducted and presented in ways that could be expected to increase stakeholder understanding of information generated thus supporting marine governance.

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