Developing Ecosystem-Based Information for Marine Spatial Planning on the Pedro Bank, Jamaica

El Desarrollo de Informaciones del Ecosistema para la Ordenación del Espacio Marítimo en Pedro Bank, Jamaica

Le Développement des Informations Écosystémiques pour la Planification Spatiale Maritime sur Pedro Bank, Jamaïque

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ABSTRACT

In the Caribbean and around the world, human use of the coastal and marine environment is placing increasing and often conflicting demands on natural resources. Marine spatial planning (MSP) has emerged globally as a strategic approach to improve decision-making and deliver an ecosystem approach to coastal and marine management. Due to a diversity of factors including the financial, technical, and human resources required for MSP, its application has been less prominent in small island developing states (SIDS) than in developed countries. In light of resource limitations, the participation of stakeholders in the creation of MSP information, including representation of spatial knowledge, can allow for the production of useful information and support understanding of the linkages between marine resources and livelihoods required for an ecosystem approach. Approximately 80 kilometers southwest of Jamaica, the Pedro Bank is one of the largest offshore banks in the Caribbean, comprises a tremendous amount of biodiversity as well as the country's most productive commercial and artisanal fishing grounds. Recently oil exploration is being undertaken on the Pedro Bank, and transportation and fishing pressure are steadily increasing. As a result of the growing demand for resources, the creation of a marine multi-use zoning design is being developed to improve Jamaica's capacity to protect, manage, and sustainably use the Bank's marine resources. Here we describe the various types of information required for MSP and methods applied to develop ecosystem-based information for the Pedro Bank within a Caribbean SIDS context.

KEY WORDS: Marine Spatial Planning (MSP), ecosystem-based management, Pedro Bank, Jamaica, Small Island Developing States (SIDS)

INTRODUCTION

In the Caribbean and around the world, human use of coastal and marine resources including transportation, fishing, tourism, recreation, oil exploration, and other activities is placing growing and often conflicting demands on natural resources. Consequently, important marine areas are under increasing pressure threatening the health of coral reefs, wetlands, mangroves, and seagrass beds and the environmental services they provide, such as coastal protection from storms, food security, and tourism-based economies. As place-based activities continue to increase, resources are being over-exploited and conflicts among users are escalating. It is clear that there is an urgent need for a process to guide sustainable development of the marine environment, one that provides for a diversity of uses while protecting biodiversity and maintaining resilience and the services people depend upon. An ecosystem approach 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).

Marine spatial planning (MSP) has emerged globally as a strategic approach to deliver an ecosystem approach to coastal and marine management (Crowder and Norse 2008). Analogous to land-use planning in the terrestrial environment, MSP aims to identify a balance between social and economic demands for development, while protecting the health and resilience of ecosystems. MSP is therefore a comprehensive multi-disciplinary planning process which lays out a spatially focused, 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). A further tenet of MSP is that stakeholder engagement is central to the process. MSP provides a transparent framework that can accommodate a wide diversity of multi-disciplinary information in an accessible format and can serve to improve stakeholder understanding and involvement in decision-making and governance (Carocci et al. 2009, Mackinson et al. 2011, Pomeroy and Douvere 2008).

MSP has emerged as an approach to help better address activities taking place in the ocean and to integrate marine management strategies (Arkema et al. 2006). One outcome of the MSP process is typically a marine multi-use zoning design (Agardy 2010, Ehler and Douvere 2009), where the boundaries of the various uses (zones) are delineated in the marine space. Thereafter, the design is translated into a zoning plan, in which acceptable uses or levels of use are defined and implemented through a set of regulations that specify allowable uses for each of the developed marine zones. Although the development of a marine zoning plan is often a central outcome of the MSP process, the two are not the same (Agostini et al. 2010). Marine spatial planning is the framework that makes comprehensive marine zoning possible (Foley et al. 2010).

As MSP has a spatial component and requires the integration of information from a variety of sources at multiple scales, the application of geographical information systems (GIS) has gained wide acceptance (Carocci et al. 2009). Yet due to a diversity of factors including the financial, technical and human resources required for MSP, its application has been less prominent in small island developing states (SIDS) than in developed countries (Baldwin et al. 2013, Pomeroy et al. in 2014). In recent years, the use of GIS as a tool coupled with participatory and collaborative approaches has emerged as a novel science known as participatory GIS (PGIS) (Chambers 2006, McCall 2003). In light of resource limitations, the participation of stakeholders in the creation of MSP information, including representation of spatial knowledge, can allow for the production of cost-effective useful information and support understanding of the linkages between marine resources and livelihoods required for an ecosystem approach (Baldwin and Mahon 2014). The employment of multi-sectoral collaborative PGIS approach, including meaningful participation in the information gathering, research, and evaluation processes, can maximize resources and management efforts thereby better guiding MSP and aiding equity and ownership in decision-making (Baldwin and Mahon 2014, Pomeroy and Douvere 2008).

The Case of the Pedro Bank

Located approximately 80 kilometers southwest of Jamaica, the Pedro Bank comprises nearly 8,000 km^2, and represents the country's most productive commercial and artisanal conch, lobster, and finfish grounds (Figure 1). The Pedro Cays are actively used as a fishing base, yet are also listed as an Important Bird and Biodiversity Area (IBA) by BirdLife International. On account of the myriad of sixteenth to seventeenth century shipwrecks and artifacts on the Pedro Bank, in 2004 the Jamaica National Heritage Trust declared the Pedro Bank a national underwater cultural heritage site. Likewise, due to its ecological, cultural, and economic importance to biodiversity and fishing, the wider Pedro Bank, Southern Channel, and Morant Cays were declared an Ecological or Biological Significant Marine Area (EBSA) under the United Nation's Convention of Biological Diversity, and a National no-take Special Fish Conservation Area was declared in 2012 around Southwest Cay. More recently, oil exploration has been undertaken on the Bank, and marine transportation is expected to increase as a result of the expansion of the Panama Canal and the potential future development of a large-scale commercial port on the south coast of Jamaica (*i.e.* Goat Islands, Jamaica). To balance the need for development with the protection of the marine ecosystem, the Government of Jamaica (GoJ) together with The Nature Conservancy (TNC) has embarked on a one year project to conduct a MSP process for Pedro Bank, Jamaica. It is anticipated that this MSP process will result in a draft marine zoning design to guide the sustainable use of the Pedro Bank's resources for the benefit of future generations, but more specifically, to provide guidance regarding where on the Bank additional protected areas should be declared.

Figure 1. Geographic location of Jamaica and the Pedro Bank and detail of the Pedro Bank (600 m isobath) MSP area.

Here we illustrate the ways a PGIS approach 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. We describe how a PGIS approach was applied to develop a range of ecosystem-based information to better understand the abundance and distribution of key marine resources and space-use patterns critical for the planning and management of Jamaica's Pedro Bank. The main intension of this paper is to demonstrate to other practitioners the manner in which PGIS can be applied to integrate, analyse and use in the development of scenarios as a starting point for MSP.

METHODS

The steps of a MSP process typically include:

i) Determining the planning area and vision,
ii) Defining uses and setting management objectives,
iii) Gathering data and information,
iv) Considering present uses and areas of overlap,
v) Determining trade-offs to identify potential management scenarios,
vi) Drafting a marine multi-use zoning design, and
vii) Developing legislation and plans for implementation and management (Beck et al. 2009).

Aspects of data collection are typically undertaken in parallel to policy development as part of the overall MSP process. In the Pedro Bank context, the process for MSP described here comprise: a preliminary appraisal, stakeholder engagement, data collection and creation, data compilation, and a demonstration of GIS applications to provide a baseline picture of the extent and distribution of marine resources, associated use patterns and the identification of threats for use in the development of various scenarios as a starting point for MSP. Methods chosen were based on the view that they should be of low cost and require limited technological expertise so that they could be widely applied in similar SIDS situations. Each of the steps and the participatory approaches adopted are briefly described in the following sub-sections.

Preliminary Appraisal

A preliminary appraisal (based on Baldwin 2012, Berkes et al. 2001) was conducted at the outset of the project to share the objectives, identify existing information and better understand the levels and types of stakeholders and institutions, and build the working relationships necessary for a collaborative (partnership) approach across the scale of the Pedro Bank. The preliminary appraisal began with an extensive literature and data search of secondary information on the distribution, uses and management of coastal and marine resources of the Pedro Bank (*e.g.* environmental and marine-related legislation, policies, management plans, GIS datasets, imagery and maps, and other collateral information). Next, meetings were held with the pre-existing Pedro Bank Management Committee (PBMC) members whom included all marine-related government agencies, NGOs, and fisher stakeholders (Mahon 2013) to explain research principles, augment objectives, share information, ascertain gaps and foster transparent collaboration. This also included visits to the Pedro Cays and key fishing villages along the south coast of Jamaica (*i.e.* Whitehouse, Treasure Beach, Rocky Point, Old Harbour Bay) known to utilise the Pedro Bank to explain the objectives and principles, identify the types of fishing stakeholders and determine their capacity for participatory research. A baseline study of the demographics of each fishing community, the locations of coastal activities, key marine resources and their current uses was also conducted through participant observation, key informant, and informal interviews with fishers (Baldwin 2014a). Furthermore, preliminary mapping exercises were conducted with fishers to assess understanding of map features (*e.g.* useful map elements, units of measurement commonly used) and determine toponymy (locally-used place names) for the Pedro Bank fishing grounds for use in subsequent data collection exercises.

Stakeholder Engagement Mechanisms

A wide collaborative approach was employed to identify data considered to be necessary for a comprehensive marine resource and space-use information system. Initially the Pedro Bank Working Group (PBWG), a multi-sectoral stakeholder group based on the PBMC members, was formed to guide the MSP process. Next a preliminary MSP workshop was conducted with the PBWG to develop a vision, identify resources, uses and stakeholders, as well as determine the objectives and goals for planning for the future of the marine resources of the Pedro Bank. Based on the identified resources, uses and stakeholders, the PBWG collaboratively determined the MSP informational needs, sources of information and methods to fill data gaps (Baldwin 2014b). Stakeholders were engaged through a variety of communication mechanisms from the outset to allow for transparent, inclusive, and equitable cross-scale interactions. This included the use of:

i) Periodic summary and validation meetings,
ii) Project summary reports,
iii) Drafts of hard-copy maps,
iv) Informational brochures,
v) Press releases,
vi) Presentations at various national committee meetings, and
vii) Via email through a dedicated internet Pedro Bank MSP Google e-group (https://groups.google.com/forum/?fromgroups#!forum/pedro-bank-msp).

Data Collection and Creation

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). Participatory research methods were employed to collect data considered to be necessary for a comprehensive information system for the Pedro Bank. Here we describe the steps we took in quantifying the abundance and distribution of existing resources and use patterns.

Marine habitat map — Marine habitat maps are a fundamental requirement for marine resource conservation and management (Norse 2010, Ogden 2010). A marine habitat map of the Pedro Bank was created in two parts (Figure 2). In 2012, the Living Oceans Foundation (LOF) and TNC conducted a number of marine surveys on Pedro Bank (*i.e.* AGGRA surveys, drop camera video and sonar tracks). Satellite imagery was acquired at two scales: a) Landsat 8 (30 x 30m) for the entire bank and b) WorldView-2 (2 x 2m) for an area of 272 km^2 focused around the Pedro Cays. Satellite images, along with the LOF field data, were used to develop two remotely sensed habitat mapping products: a) a broad scale habitat map (six classes) for the entire Pedro Bank up to the 30 metre bathymetry contour based, and b) a fine scale habitat map (10 classes) and associated bathymetry products around the Pedro Cays and near-shore area.

Accuracy assessment — Marine field surveys were undertaken to validate and assess habitats derived from the remotely-sensed imagery. A stratified random sampling design, guided by recommendations of remote-sensing experts, was used to determine survey sites. Selected sites were accessed from a fishing boat (local 7 m bighead canoe) and located using a handheld Garmin MapCx76 GPS. At each site, the habitat class was assessed using snorkel or SCUBA gear and photographed using a GoPro underwater camera. Additional information including a textual description of the habitat, list of key species observed, and an estimate of benthic cover or density of habitat (percent cover) was recorded.

A participatory validation step was undertaken with Pedro Cays fishers having an intimate knowledge of marine habitats. To aid understanding amongst fishers, the local names of fishing banks and other descriptive information such as map scale (in miles), the mainland of Jamaica labelled with major landing sites, bathymetry contours (in fathoms), and a compass rose were overlain on the broad-scale habitat map (Figure 2). Time was taken to carefully explain the map's features and orientate the fishers before allowing them to review and assess the habitat map. Additionally cross-validation exercises with the location of fishing activities were also conducted to assess accuracy of the derived habitat map.

Mapping resources and space-uses — Participatory research methods (*e.g.* socio-economic surveys, mapping exercises, marine field surveys) were employed to solicit and incorporate spatially-based local knowledge within the geodatabase and fill information gaps on human use. To start, a number of semi-structured interviews were held with PBWG stakeholders and other identified key informants to collect identified resource and space-use information (*i.e.* Dr. Ann Sutton regarding sea birds and turtles, Dr. Karl Aiken regarding previous fisheries research, Commanding Chief of the Coast Guard regarding illegal fishing activities). A part of the questionnaire comprised a mapping exercise component, with a pictorial legend of features, to guide expert mapping exercises of space use patterns (*e.g.* anchorages, shipping lanes, recreation), the distribution of key resources (*e.g.* seabird and sea turtle nesting sites, cultural/ historical sites).

Next, a rapid fishing resource use assessment (drawing upon Baldwin 2012, Bunce and Pomeroy 2003) was conducted using semi-structured interviews to better understand the abundance and space-use profiles of Pedro Bank fishers. Based on data collected from both the Fisheries Division and the preliminary assessment, we aimed to sample approximately 15% of fishers stratified by fishing base (*i.e.* Pedro Cay, mainland Jamaica) and fishing gear (*i.e.* line, net, trap, free diving, compressor diving). An effort was also made to speak with industrial fishing companies and carrier boat owners. Questionnaires sought information on demographics, livelihood strategies, resources and use patterns. As part of the questionnaire, a mapping exercise component was included to collect spatial data. Interviews and mapping exercises were conducted in private (*i.e.* at the research station) using a questionnaire and hard-copy basemap of the Pedro Bank overlain with the local names of key fishing banks and information such as map scale (*i.e.* miles), the mainland of Jamaica labelled with major landing sites, bathymetry

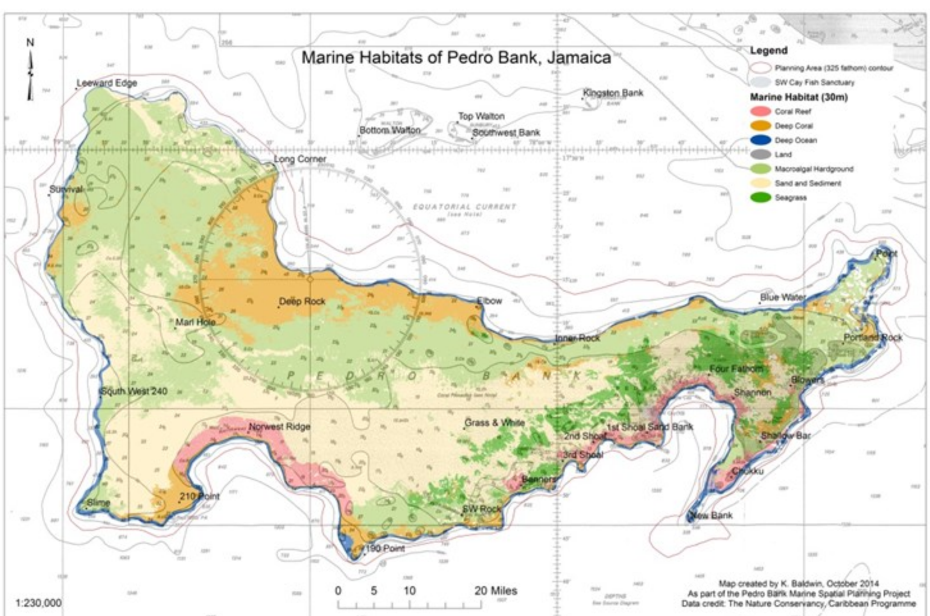

Figure 2. Pedro Bank broad-scale habitat map annotated with topology, compass rose, scale bar and bathymetry isobaths contours used in mapping exercises.

contours (*i.e.* feet and fathoms) and a compass rose. At the start of each mapping exercise, time was taken to carefully explain the purpose of the interview and explain the basemap's features to orientate fishers and allow for understanding of the map. Drawing upon Hackett et al. (2014), the spatial extent of fishing grounds and priority fishing areas were mapped for each fisher. Based on discussions of the Pedro Bank habitat basemap and the local names of fishing grounds, fishers were guided to draw a box on the basemap to represent the maximum extent (north, south, east, and west) of their fishing grounds. Next, fishers were asked to identify within their maximum fishing extent, the areas of highest importance over their cumulative fishing experience and to rank these using a weighted percentage (*e.g.* an imaginary '1000 dollars') that they distributed over the fishing grounds. Lastly, several open-ended questions were included to obtain information on areas of conflict, Illegal, Unreported and Unregulated (IUU) fishing, and perceptions about conservation areas. Recommendations on potential locations for new conservation areas and types of fishing zones to be applied on the Pedro Bank were also mapped. We aimed to keep interviews less than one hour in length, although many times discussion continued for a longer period. Each day the number of and types of fishers interviewed were tallied to ensure a representative sampling effort. Each fisher was assigned an identification number, and each mapping exercise basemap was photographed annotated with the date, fisher's name, and fishing base.

Data compilation and processing — The geodatabase design was driven by the need to understand the environment and influence of human activities to support the MSP for the Pedro Bank. The geodatabase was created using ArcInfo version 10.1 software. All data were imported and standardised using ArcMap, ArcCatalog, and ArcToolbox along with the Spatial Analyst extension. Data were organised into feature datasets or similar 'themes' comprising of conservation, fishing, transportation, future uses, and threats each of which contain a number of corresponding feature classes or 'layers' categorised by name, geometry, source and geo-processing performed.

Much of the collected spatial data required additional processing and preparation into thematic layers. Imagery, nautical charts, maps, and existing GIS data determined to be of use were imported into ArcGIS, clipped to extent of the Pedro Bank planning area, and re-projected if necessary to a common coordinate system. The fisher space-use assessment (socio-demographic surveys and spatial mapping exercise data) were translated into GIS. Socio-demographic and other questionnaire attribute information were entered into Excel, the spatial extent of fishing grounds were digitized from basemaps and table joins used to connect attribute information with spatial profiles for each fisher. Data was either downloaded, as in the case of the exclusive economic zone and seabird foraging tracks, created by measuring a set distance from the coastline (using the Buffer tool), as in the case of pollution features, or digitised by importing GPS coordinates, as in the case of the no-take fish sanctuary. 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 GPS unit. Corresponding attribute information was obtained using textual information on nautical charts and maps, reports, phone calls, informal conversation, and personal observation and referenced accordingly in the metadata.

Review, evaluate and refine MSP objectives and goals — A second planning workshop was held with the PBWG to share findings, obtain feedback and support transparent cross-scale learning amongst stakeholders. Several exercises enabled the group to review new information collected and discuss means to fill the remaining data gaps (Baldwin 2014b). Based on the findings of the data collection and fieldwork, the vision, objectives, and goals for the Pedro Bank were re-evaluated by the PBWG and adapted accordingly.

RESULTS

MSP planning workshops and more than 90 key informant interviews including 78 semi-structured interviews with Pedro Bank fishers (40 Pedro Cays, 31 Jamaican mainland, six industrial fishing companies) were conducted. Based on the identified resources and uses for the Pedro Bank, a list of anticipated features to be mapped, sources of information and methods for data creation were collaboratively developed by the PBWG (Table 1). Collecting data, defining the geodatabase structure and populating the geodatabase was an iterative process initially taking about six months, and will continue throughout the remainder of the project (additional six months). A total of four satellite imagery datasets, three nautical charts, 57 technical reports many containing maps or atlases, and more than 40 GIS files were collected and reviewed for use. Ultimately the Pedro Bank geodatabase consisted of 8 feature datasets, comprising 39 feature classes (Table 1), of which 62% was derived in part, based on the use of local knowledge sources.

Information Created 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). To illustrate, we demonstrate some practical GIS applications that serve to define and analyse the basic requirements for the Pedro Bank MSP process.

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 habitats occurring on the Pedro Bank. Likewise, 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 the only offshore no-take fish sanctuary (*i.e.* Southwest Cay) with coastal and marine habitat has allowed for:

i) An inventory of habitat located within each conservation area,
ii) An assessment of the amount of each habitat type afforded protection as compared to the total amount occurring on the Pedro Bank, and
iii) An evaluation of the 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).

One benefit of GIS is that it provides users with the ability to easily create maps, providing a better understanding of the interactions occurring within a particular environment. Maps of the coastal marine resources and human activities occurring near the Pedro Cays were created to allow for increased understanding of the amount of resources afforded and corresponding human activities in the area. The Pedro Cays resource and activity map shows a variety of marine and coastal habitats represented, including salt pond and small stands of mangrove. There are two sea bird nesting areas, three sea turtle nesting beaches, a number of fish nursery areas, four shipwrecks, one cannon, and a lighthouse. Human activities include three fish landing sites, two areas where baitfish are harvested, two anchorages, three sources of pollution, and

Table 1. Pedro Bank MSP feature layers created categorized by zone, feature datasets, name, methods and source(s).

Zone	Feature dataset	Layer name	Methods	Source(s)
CONSERVATION	Habitat	Shallow Coral Reef	Remote sensing & field measurement	The Nature Conservancy, S. Purkins
		Deep Coral Reef		
		Sand and Sediments		
		Seagrass		
		Macroalgal Hard Bottom		
		Deep Ocean		
		Wetlands (Mangroves/Salt Pond)	Digitised from imagery, reports	WV2 imagery (2014), Pedro Cays Management Plan
	Resources	Seabird nesting areas	Existing data & reports	Seabird Management Plan
		Seabird foraging areas		P. Jodice (satellite tracking data)
		Sea turtle nesting beaches		Pedro Cays Management Plan
		Conch grounds	Density surface model	Conch assessment survery (2012)
		Lobster grounds	Habitat Proxy	Deep reef & Macroalgal hardground
		Nursery areas	Mapping exercises	Fishers
		Baitfish bays		
		Spawning sites	Modelled surface	TNC Potential SPAGs (W. Heyman model)
		Biophsical parameters (upwelling, SST, Chl a)	Modelled surfaces	NOAA global datasets
		Cultural/Heritage Sites (shipwrecks)	Digitise features	Nautical charts, JNHT
	Management	Marine protected areas (proposed)	Mapping exercises	Fishers
		Fish sanctuaries (designated)	GPS coordinates	The Nature Conservancy
		Scientific research areas / data collection	Digitise features	Conch survey sites (2011), AGGRA sites
FISHING	Fishing grounds	Extent of industrial fishing grounds (conch)	Vessel tracking	CRFM (no data for lobster)
		Extent of artisinal fishing grounds	Mapping exerscises	Fishing extent (all gears combined)
	Fishing gear	Traps	Mapping exercises	Fishers (artisinal) extent (frequency) by gear & fishing base
		Compressor		
		Free Lung		
		Line		
		Nets		
	Fishing pressure	High priority fishing banks (artisinal)	Weighted overlay analysis	Fishing priority modelled surface
		Fisher (socio-deomgraphic) profile	Excel table	Fisher surveys, Fisheries Division
TRANSPORTATION		Shipping routes	Downloaded	NOAAs SEAS BBXX dataset
		PSSA (for designation)	Pedro planning area	Scope of planning area (600 m)
		Anchorages	Mapping exercise	Nautical charts, fishers, Fisheries Division
		Fish landing sites		
		Military areas	Mapping exercise	Coast Guard
FUTURE USES		Potential oil extraction	Digitise features	Petroleum Corporation of Jamaica
		Eco-tourism (wildlife viewing, diving, research)	Mapping exercises	Yardies
THREATS		Invasives (cats / rats / crabs)	Digitise features	Pedro Cays Management Plan, experts
		Sources of pollution (land-based & marine)	Mapping exercises	Pedro Cays Management Plan, fishers
		Illegeal (IUU) fishing	Mapping exercises	Fishers, Coast Guard

an area with the potential for ecotourism. Even without any spatial analyses, these maps illustrate the diversity of resources and uses occurring in the proximity of the Pedro Cays.

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. Based on the fisher assessment surveys, a socio-demographic profile of Pedro Bank fishers was created. The average age of a Pedro Bank fisher is 44 years, with 26 years of fishing experience. Eighty-six percent of fishers have no other livelihood, and typically fish 10 months of the year of which nine months are spent on the Pedro Bank. Spatial representation of fishing grounds by fishing base show several patterns which may not be apparent from summary statistics alone. Distinct spatial fishing patterns emerge both by fishing base (Figure 3a) and gear (Figure 3b). These findings may have several important implications for MSP in relation to the evaluation of management scenarios and determination of zoning trade-offs.

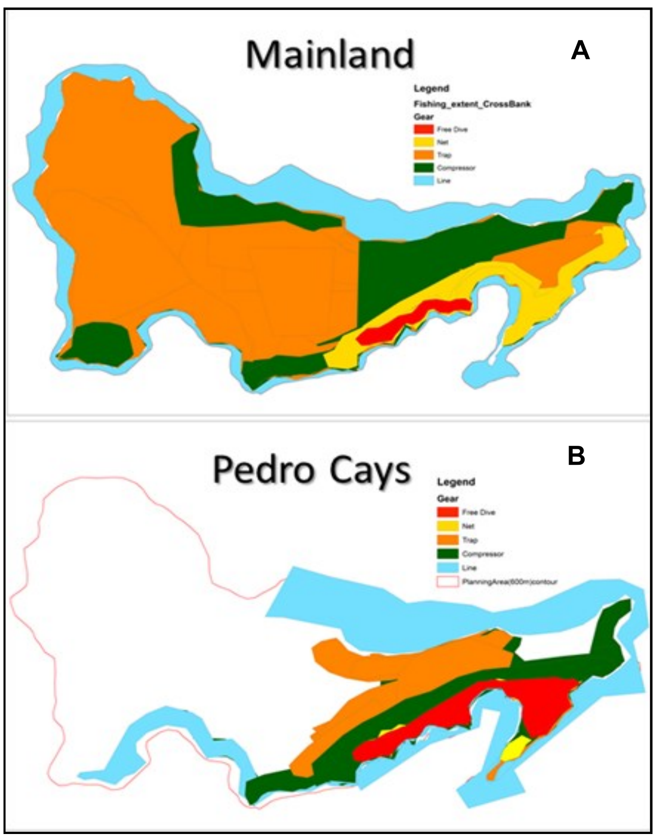

Figure 3. Comparison of spatial fishing patterns by fishing gear emerging on the Pedro Bank. Figure 3(a) depicts the extent of fishing grounds of fishers based from the mainland of Jamaica; and (b) depicts the extent of fishing grounds of fishers based from the Pedro Cays.

Attitudes on conservation, fishing and management — The largest threat to the marine resources of the Pedro Bank reported by fishers relates to IUU fishing activities. Large amounts of IUU fishing (*e.g.* poaching) by foreign vessels was reported to occur on the western half of the Bank (*e.g.* Banners Reef, Southwest Rock, Northwest Ridge, 190 Point and 210 Point). Other conflicts reported include IUU fishing activities by Jamaican fishers (*e.g.* night-fishing with compressor, fishing in the sanctuary, landing of undersized fish and berried lobsters, lack of respect for closed seasons). As a result of this threat, the majority of fishers are calling for increased enforcement of fisheries regulations across the Bank. Regardless, all fishers interviewed were aware of the Southwest Cay fish sanctuary and regulations. The vast majority (89%) recommend that more sanctuaries should be established on the Pedro Bank and consider the protection of fish nursery and breeding habitat was the foremost reason a fish sanctuary should be established. Five fish sanctuary sites were proposed by fishers. Additionally, the application of seasonal closures or 'giving fishing grounds a rest' was a popular management measure recommended by 41% fishers surveyed. GIS analyses can be applied to evaluate the representativeness of these proposed areas. This type of information can contribute to MSP through the determination of feasible potential conservation zones supported by fishers. This approach may meet with little resistance from fishers, thereby assisting management acceptance and compliance. 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.

Review, Evaluate and Refine MSP Objectives and Goals

A second MSP workshop was conducted to review data and information collected, re-evaluate, and revise the Pedro Bank MSP objectives and goals. Consequently, the Pedro Bank marine planning area was extended to the 600 m (1,850 feet / 328 fathoms) bathymetry contour to accommodate the spatial extent of all Pedro Bank fishing grounds. Similarly, the original uses (zones) to be planned for were revised. The PBWG determined that the MSP should seek to plan for conservation, fishing, and future development uses and that research, education, and tourism are compatible with and should occur within each of the developed zones. Furthermore, in light of the ESBA designation, the PBWG agreed that a transportation *zone* will not be planned for and full support to designate the Pedro Bank as an IMO Particularly Sensitive Sea Area (PSSA) will be pursued.

DISCUSSION

This study tested the practical application of PGIS in a Caribbean marine SIDS context to support an ecosystem approach to marine management. We found the application of PGIS resulted in the production of comprehensive information tailored to the needs of the Pedro Bank stakeholders. The PGIS process also served to strengthen cross-scale linkages, promote a transparent and inclusive working environment, and build capacity for adaptive learning. Here, we provide a brief assessment of lessons learned, and illustrate how PGIS can strengthen MSP and marine governance. Lastly, we discuss considerations for the implementation of the Pedro Bank MSP in Jamaica.

Applicability of a Collaborative Approach

A PGIS approach including the use of participatory research demonstrated the relevance and value of information provided by stakeholders. It also supported an ecosystem approach through the use of multi-disciplinary and multi-knowledge information sources for management, corroborating the findings of Baldwin et al. (2013), Christie and White (2007), and DeFreitas and Tagliani (2009). The use of stakeholder feedback to develop the objectives of the MSP, refine the research methods, identify secondary data sources, and produce relevant information is thought to have been of key importance. Consulting with stakeholders before each stage of the research and seeking feedback allowed for adaptation of research methodologies and the objectives of the MSP process to be revised. Mapping exercises allowed for the systematic collection of stakeholders spatial knowledge of resources and use patterns. Combining the socio-economic survey information with mapping exercises allowed for the creation of spatially-based information. Additionally, the distribution of maps and summary reports together with validation meetings had several benefits. First, it allowed for the production of accurate information based on local knowledge. This further demonstrated to stakeholders the legitimacy of their knowledge, and thereby promoted ownership of the information produced. Second, this collaborative working environment together with the use of transparent communication and information access mechanisms promoted trust and ownership in the research and information produced. It ultimately legitimised involvement by demonstrating the usefulness of local knowledge and substantiating the capacity and willingness of stakeholders to participate in marine governance.

Difficulty Planning for Future Uses

The potential for future development (*e.g.* oil extraction, tidal energy, ecotourism) provided the most challenging use to plan for in the Pedro Bank context. There was either a lack of existing information on the potential of future uses or access to existing information was not released for use in the MSP process. Thus, stakeholders found it problematic to incorporate the unknown value of a *potential development* including the determination of associated trade-offs and impacts of unknown uses. Consequently a focus on planning for the present uses of the Pedro Bank marine resources prevailed in this MSP process. Despite this limitation, PBWG stakeholders reckon that the range of ecosystem-based information produced through this MSP process will be of use to better guide future development of the Pedro Bank in a sustainable manner.

CONCLUSION

The usefulness of integrating interdisciplinary, multi-knowledge information for ecosystem-based MSP is well documented (Pomeroy et al. 2014, Pomeroy and Douvere 2008, Dalton et al. 2010, Tallis et al. 2010). However, the actual framework and practical methodologies for achieving holistic ecosystem-based information are lacking (Baldwin and Mahon 2014, FAO 2013). We found a PGIS approach useful for collaboratively collecting, integrating and understanding multi-knowledge interdisciplinary information. It presented a variety of valuable opportunities for informed decision-making and realising a feasible MSP for the Pedro Bank. Aside from the fact that a large proportion (62%) of information in the geodatabase was derived from local knowledge, in particular information on human activities, we demonstrate a number of practical GIS analyses that can be 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 proved beneficial in that it allowed for spatially-based ecosystem-level analyses of the Pedro Bank to be conducted and presented in ways that could be expected to increase stakeholder understanding of information generated thus supporting participation in marine governance. Lastly but just as important, a PGIS approach provided fisher stakeholders with a level of legitimacy and recognition of their knowledge that is rarely afforded and subsequently promoted trust and ownership in the research and information produced.

In conclusion, a suite of accompanying activities will be necessary to support the implementation of the Pedro Bank MSP. This requires the development of an effective national integrated marine management structure in Jamaica, management plans for each of the developed zones, and a legal analysis to address any revisions to existing regulations and policies that may be needed. Additionally, effective management of the Pedro Bank marine resources is compounded due to its remote location to the mainland of Jamaica, limited infrastructure, and the capacity to enforce and combat the large amount of IUU fishing presently occurring. Therefore, consideration to develop a collaborative management, monitoring, and evaluation program to strengthen the capacity for enforcement and management of this area should be a priority.

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