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Marine spatial planning on the Caribbean island of Montserrat: Lessons for data-limited small islands

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Abstract

As human use of the oceans increases, marine spatial planning (MSP) is being more widely adopted to achieve improved environmental, economic, and social outcomes. However, there is a lack of practical guidance for stakeholder driven, scientifically informed MSP processes in small island and data-limited contexts. Here, we present an overview of MSP on the Caribbean island of Montserrat, with a focus on the scientific and technical input that helped inform the process. Montserrat presents an interesting case study of MSP in the small island context as it has ocean uses that are common to many islands, namely small-scale fisheries and tourism, but the marine environment has been heavily impacted due to volcanic activity. We detail the methods for data collection and analysis and the decision-making process that contributed to a marine spatial plan. We highlight aspects of the process that may be useful for other small islands embarking on MSP, and lessons learned regarding scientific support, including the need for on-site scientific support and guidance throughout MSP, the importance of setting clear objectives, working within data limitations and making data accessible, and choosing and using appropriate decision support tools.

KEYWORDS

Caribbean, marine protected areas, marine spatial planning, marine zoning, Montserrat, MPA, MSP, small islands, sustainable ocean management

1 | INTRODUCTION

The world's coasts and oceans are increasingly crowded. The number of people living in the coastal zone (i.e., the contiguous coastal area below 10 m elevation) is expected to grow from 625 million in 2000 to between 879 and 949 million by 2030 (Neumann, Vafeidis, Zimmermann, & Nicholls, 2015), placing more pressure on the nearshore marine environment. Industrial fisheries occur in >55% of total ocean area (Kroodsma et al., 2018) and aquaculture, offshore wind farms, and global shipping have all expanded rapidly in the 21st century (McCauley et al., 2015), leaving few marine environments untouched (Jones et al., 2018). To balance the needs of different ocean users and management objectives, marine spatial planning (MSP) provides a multisector, place-based approach to analyzing and allocating human activities in marine environments (Ehler & Douvere, 2009; Lester et al., 2018). If implemented effectively, MSP can minimize ocean-use conflicts while conserving biodiversity and ecosystem services (Day, Kenchington, Tanzer, & Cameron, 2019; Lombard et al., 2019). MSP has been widely used in developed countries, particularly in Europe and the USA (Ehler & Douvere, 2010). There has been less focus on MSP in small islands and developing nations, perhaps in part due to the practical problems of implementing MSP in these areas and a lack of examples to follow (McConney & Chuenpagdee, 2011; Pomeroy, Baldwin, & McConney, 2014). A number of Caribbean islands, including St. Kitts and Nevis (Agostini et al., 2015), Dominican Republic (Romero, Tejo, & Schill, 2012), Barbuda (Pomeroy et al., 2014), and the Grenadine Islands (SusGren, 2012), have engaged in MSP processes to help balance competing ocean uses and objectives, but few have gone beyond the planning stage.

Despite the lack of examples in small island contexts, there is a clear need for MSP. Small islands have economies and cultures that are tightly linked with their marine environment (Bell et al., 2009; Keen, Schwarz, & Wini-Simeon, 2018). They also often have exclusive economic zones that are many times larger than their land areas, making it challenging to manage their marine resources (Jumeau, 2013). The small-scale fisheries on islands are often an important source of food and income, and provide an economic safety-net in times of hardship or following natural disasters (Béné, Hersoug, & Allison, 2010; Pauly, 2006). Tourism that often forms a large part of island economies (Pratt, 2015) is heavily focused on coastal areas and marine activities such as swimming, snorkelling, diving, and boat trips. Many islands are also investigating the potential to develop new ocean industries, such as offshore aquaculture or wind energy (Greenhill, Day, Hughes, & Stanley, 2016; Teneva, Schemmel, & Kittinger, 2018), and MSP can provide more certainty to potential investors (European Commission, 2011). Additionally, there is considerable focus on the creation and expansion of marine protected areas (MPAs) to conserve islands' natural resources and to meet international commitments (Toonen et al., 2013), and MPAs are often a central part of a zoning process. Apart from zoning current marine activities, MSP can also help islands pre-empt future ocean use conflicts by designating areas available for certain industries, activities, or management objectives.

One of the common hurdles to MSP is the need for diverse spatial data, including information regarding cultural, economic, ecological, and social values. For developed countries, multiple spatial datasets are often already available or there is funding available to collect them. For example, more than 60 data sets were available for the process of rezoning the Great Barrier Reef (Fernandes et al., 2005). In contrast, smalls islands, particularly those classified as developing states, often have limited spatial data and little funding for data collection (Ban, Hansen, Jones, & Vincent, 2009; Gill, Oxenford, Turner, & Schuhmann, 2019). Global and regional scale datasets (e.g., bathymetry, global habitat datasets) typically do not have sufficient spatial resolution to inform MSP on small islands. Therefore, the MSP process often requires collection of new data sets and the use of decision support tools that can be used within the constraints of limited data.

Here, we present an overview of the MSP process that was recently undertaken on the Caribbean island of Montserrat, where a marine spatial plan is under consideration by the government. Montserrat presents an interesting case study for MSP because of factors it has in common with other small islands, such as limited data, as well as the unique aspect of continued volcanic activity, which limits access to some nearshore areas. We detail the decision-making process and methods for data collection and analysis that contributed to the marine spatial plan in Montserrat, with a focus on scientific input into the zoning process. We evaluate the process and highlight lessons learned that could inform MSP on other small islands.

2 | STUDY SITE

Montserrat is a volcanic island in the northeastern Caribbean, 45 km southwest of Antigua with a population of 4,490 (pers. comm. Statistics Department of Montserrat, March 21, 2019). The island has a total land area of 102 km^2 and 49 km of coastline. Montserrat's shelf area out to the 100 m depth contour is approximately 141 km^2, with most of the shelf area to the north, east and west sides of the island, while the southern end of the island drops off steeply (Figure 1). The shelf seafloor is dominated by sand and algal reefs, with coral reefs found along the east and northeastern sides of the island, and a thin strip of reef along the southeast coast (Estep et al., 2018). The "coral reefs" actually have relatively low coral cover, averaging 10% (Estep et al., 2018), compared to a Caribbean wide average for 2001–2005 of 16% (Schutte, Selig, & Bruno, 2010), and are dominated by turf algae (Estep et al., 2018). Little is known about the benthos deeper than 100 m, however recent surveys suggest that there are extensive algal reefs, with some mesophotic coral reef communities (Estep et al., 2018).

Montserrat has suffered from significant natural disasters in recent decades, including hurricane Hugo in 1989 (Berke & Wenger, 1991) and the eruption of the Soufrière Hills Volcano from 1995 to 2010 (Coussens et al., 2017). The nearshore ecosystem, including the coral reefs, has been impacted by pyroclastic flows and ashfall from the volcano (Myers, 2013); however, due to a lack of survey data from before the volcanic activity, the effects have not been quantified. An exclusion zone surrounding the volcano covers approximately the southern two-thirds of the island with entry strictly controlled (Figure 1; zone V). Maritime exclusion zones, where boats can pass only in the daytime without stopping, are found on the east and west sides of the island (Figure 1; zones W and E; MVO, 2018).

Montserrat is a UK Overseas Territory, and since the devastation caused by the volcanic eruptions the economy has been heavily dependent on support from the UK Department for International Development (Mott MacDonald, 2018). Tourism contributes an estimated 5% to GDP, while the fisheries sector makes up less than 1% (Mott MacDonald, 2018). The Government of Montserrat has plans to increase the size of the tourism sector (CHL Consulting, 2012) and sustainable fisheries production (Ponteen, 2014).

Montserrat's small, artisanal fishery targets coral reef, demersal, coastal pelagic, and pelagic species. Fish traps and nets account for over 90% of fisheries landings, with traps being used to catch coral reef and demersal species, and nets for coastal pelagic species, mainly from the family Belonidae (Sustainable Fisheries Group, 2016). An estimated 90% of fishing occurs within 4.8 km (3 miles) from shore, and all catches are for subsistence or for sale on the local market; there is no export market (Ponteen, 2014). The majority of reported catch is landed at Little Bay or Carr's Bay, with other landing sites at Bunkum Bay, Old Road Bay, and Isle's Bay (Figure 1). In 2015, there were 34 active fishers and 29 active vessels (Sustainable Fisheries Group, 2016). There are several other ocean uses within Montserrat's waters, including diving, snorkeling, sport fishing, yachting, and shipping. There are two scuba diving operators as well as a snorkeling and kayak tour operator. Compared to other

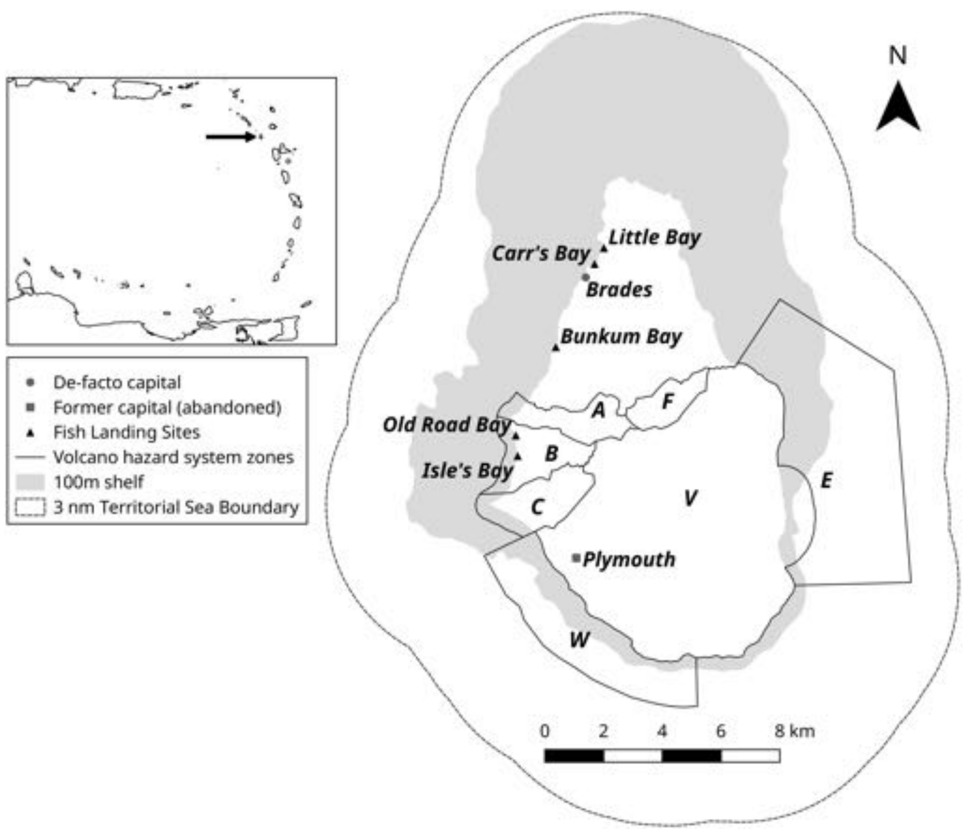

FIGURE 1 Map of Montserrat. Inset map shows location of Montserrat (indicated by arrow) in Lesser Antilles island chain. Main map shows Montserrat's 3 nautical mile Territorial Sea boundary, 100 m shelf, the de facto and former capital cities, fish landings sites, and the volcano hazard zones. At hazard level 1 (as of July 25, 2019), zones A, B, C, and F allow unrestricted access, zone V allows controlled access, and maritime zones E and W allow daytime transit only. For current hazard level see www.mvoms.org

destinations in the Caribbean, Montserrat has few yacht and cruise ship visitors, with an average of 1,535 and 3,775 visitors/year, respectively for the period 2015–2018 (pers. comm. Montserrat Tourism Division, June 7, 2019). Shipping and boat traffic, including an inter-island ferry, cargo and cruise ships, must all use the port facilities at Little Bay, though there is also limited sand export from the jetty at Plymouth.

3 | OVERVIEW OF PLANNING PROCESS

In February 2015, the Government of Montserrat and the Waitt Institute launched Blue Halo Montserrat as a partnership to develop and implement solutions for sustainable ocean management through MSP, fisheries management, and community stewardship. The Government of Montserrat had a specific interest in improving fisheries catches and strengthening coastal livelihoods. During the United Nations Ocean Conference in June 2017, the Government committed to protecting 10–30% of its marine environment in no-take marine reserves (Government of Montserrat, 2017).

The Blue Halo Steering Committee (henceforth "the Committee") was established as an advisory body to guide the MSP process, and was comprised of representatives from government, nongovernment, and private sector interest groups (Table 1). The Committee's decisions provided guidance to Montserrat's Minister of Agriculture, Trade, Lands, Housing, and Environment (MATLHE) who had ultimate responsibility for the marine spatial plan that would be put forward to legislators. Committee members played an important role as ambassadors for the project, providing information about planning to their organizations and the community more broadly, and taking feedback from those people back to Committee meetings. The Committee met regularly to review progress on the project and develop draft-zoning plans. To aid decision-making, the Committee received scientific advice and technical assistance from the Waitt Institute, and the McClintock Lab (developers of seasketch.org) and Sustainable Fisheries Group at the University of California Santa Barbara (henceforth "Science Advisory Team").

The MSP process with the Committee started in 2017, although preparatory work for MSP, including data collection, and scientific review and analysis of data, started in 2015. Over a series of nine meetings, the Committee reviewed available data, received advice from the Science Advisory Team, and developed initial marine zoning options, resulting in a plan that was released for a first round of public consultation and comment (Figure 2). The Committee, with assistance from the Science Advisory Team, revised the plan based on public feedback, and this plan was put out for a final round of public consultation. Based on this feedback, the Committee produced three options that they then voted on. Due to an almost evenly split vote, the three options were submitted to MATLHE to select the final plan. At the time of writing, the marine spatial plan was pending cabinet review. Here we discuss MSP and the scientific input into the process, specifically: (a) data collation and tools, (b) setting objectives, (c) conservation prioritization analysis, and (d) the zoning process.

TABLE 1 Composition of the Blue Halo Steering Committee

Government	Nonprofit and interest groups	Private sector
Department of Agriculture	Fisheries Association	Aqua Montserrat
Department of Environment	Fisheries Cooperative	Scuba Montserrat
Attorney General Chambers	Montserrat National Trust	Island Dive Center
Port Authority	Coral Cay Conservation	
Airport	Farmers Association	
Fisheries Division		
External Affairs		
Physical Planning Unit		
Department of Tourism		
Customs		
Police		
Montserrat Volcano Observatory		

4 | DATA COLLATION AND TOOLS

Before MSP could begin, we assessed what datasets were available to inform the planning process. We obtained spatial data on demography, hazards, infrastructure, land cover, natural heritage, physical geography, and tourism from the Government's GIS Centre, and fisheries data, including catch data extending back to 1994, from the Fisheries Division. To provide an overview of all data and identify gaps, we conducted a comprehensive literature review of the ecology and economics of Montserrat's marine resources (Sustainable Fisheries Group, 2015). A lack of data on the marine environment

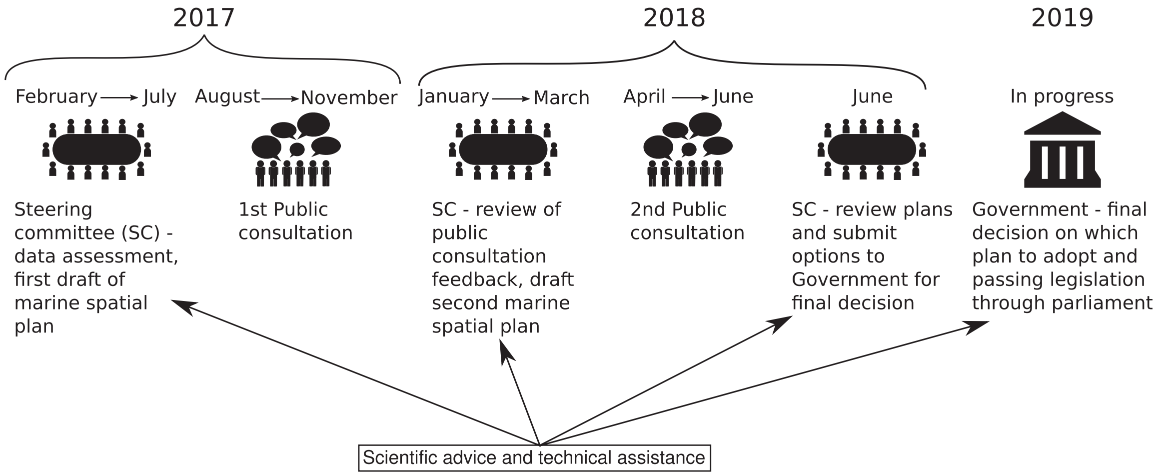

FIGURE 2 Timeline and stages of marine spatial planning decision-making process in Montserrat

prompted additional data collection that included: (a) a rapid marine scientific assessment to characterize Montserrat's marine habitats, benthic cover, and fish communities (Estep et al., 2018), (b) ocean use surveys of stakeholders to determine the spatial distribution of fishing and diving activities, and (c) community consultations to engage with residents and understand local priorities for ocean management (Waitt Institute, 2016a).

The ocean use surveys provided spatial information used in the MSP process. We conducted the in-person surveys using SeaSketch (Seasketch, 2016), a decision support platform with sketching tools for collecting map-based surveys and contributing to planning. Survey participants were chosen using a snowball method (Huck, 2000), starting with individuals identified by the Committee as having close ties to the ocean (e.g., fishers and divers). We interviewed 122 individuals and asked them to indicate areas within the study region that they used for fishing ($n = 53$) and diving ($n = 69$) and to assign relative value to these areas by distributing 100 points amongst areas for each activity. From this, we developed heat maps showing the distribution of fishing and dive site value across the study region (Figure S1).

We made all spatial data layers used for the process publicly available in the SeaSketch web platform (montserrat.seasketch.org). Members of the public and the Committee could access SeaSketch to view layers and draw boundaries of prospective zones, including no-take and partial-take MPAs, port authority zones (i.e., shipping lanes), mooring and anchorage zones, multi-use zones (i.e., status quo), and recreation zones. In addition to providing remote access to the mapping tools, SeaSketch was used to facilitate Committee meetings throughout the process, focusing the conversation on agreed upon data and information.

5 | SETTING OBJECTIVES

A vital step in any spatial planning process is defining the goals and objectives (Ehler & Douvere, 2009). In Montserrat's case, the goals were stated in the Memorandum of Understanding (MoU) between the Waitt Institute and the Government of Montserrat: "identify individual and shared actions to achieve ocean zoning, designation of sanctuary zones, sustainable fishing, and other measures to ensure long-term health of Montserrat's waters." Recommendations for MSP, such as designating 30% of Montserrat's waters as no-take MPAs, protecting seagrass and coral reef habitats, and designating shipping and mooring zones, were subsequently provided to the government (Waitt Institute, 2016b). The Science Advisory Team also presented information regarding best practices for MPA design to the Committee, including the common recommendation of protecting 30% of each major habitat type to help ensure sustainable ocean use (Krueck et al., 2017; World Parks Congress, 2014), and practical recommendations such as using straight lines for zone boundaries and simple shapes for zones, which can improve compliance and enforcement (Fernandes et al., 2005; Lewis et al., 2017). Although the ideal area to protect is dependent on the specifics of a location and the MSP objectives, reserve sizes that provide conservation and fisheries benefits have consistently been found to be in the 20–40% range (Gaines, White, Carr, & Palumbi, 2010; Krueck et al., 2017; O'Leary et al., 2016).To develop specific objectives relevant to Montserrat, the Science Advisory Team worked with the Committee to produce a list of 11 conservation objectives (Table S1). The Committee reached general agreement on the use of three key objectives from this list: (a) maintain or enhance biomass of species targeted by fisheries; (b) protect species diversity; and (c) conserve live coral and healthy reefs. The full list of objectives had considerable overlap, therefore the intention was never to use all, but to allow the Committee choice in selecting those that they viewed to be most important. The Committee then requested scientific guidance on which areas should be prioritized for inclusion in MPAs to achieve the three objectives. The Science Advisory Team responded to this need by producing a map of priority conservation areas that achieved the specified objectives.

6 | CONSERVATION PRIORITIZATION ANALYSIS

To select priority conservation areas using a repeatable, transparent, and scientifically credible method, we implemented a systematic conservation planning approach using the R package *prioritizr* (Hanson et al., 2018*)*. Prioritizr, and other similar optimization tools such as Marxan (Watts et al., 2009), require several inputs, which we selected as follows:

1. Project area and planning units—The project area was defined as the area within the 100 m depth contour around Montserrat because this was the area for which we had biodiversity data from the scientific assessment. This area was rasterized to produce a grid of 12,795100 m^2 cells which were used as the planning units.
2. Biodiversity features—(a) We used a benthic habitat map (Figure 3a) to assess protection of each habitat type. The habitat map covers 0–100 m depth and was developed during scientific surveys completed in 2014–2015 (Estep et al., 2018). There are seven benthic habitat categories that describe both geological form and biological cover: algal reef, artificial reef, colonized volcanic boulders, coral reef, hard bottom/ sand, sargassum forest, and seagrass; (b) We included the summed coral and fish species richness as a second biodiversity input (Figure 3b). Reef data from scientific surveys completed in 2014–2015 (Estep et al., 2018) were used to map coral and fish species richness around the island. These point data were interpolated to a 500 m radius and constrained to the 100 m shelf area.
3. Targets for biodiversity features—For benthic habitat, the target was to protect 30% of each habitat type. For species richness (after testing multiple options for protection, see Figure S2), we set a target of protecting 50% of summed coral and fish species richness.

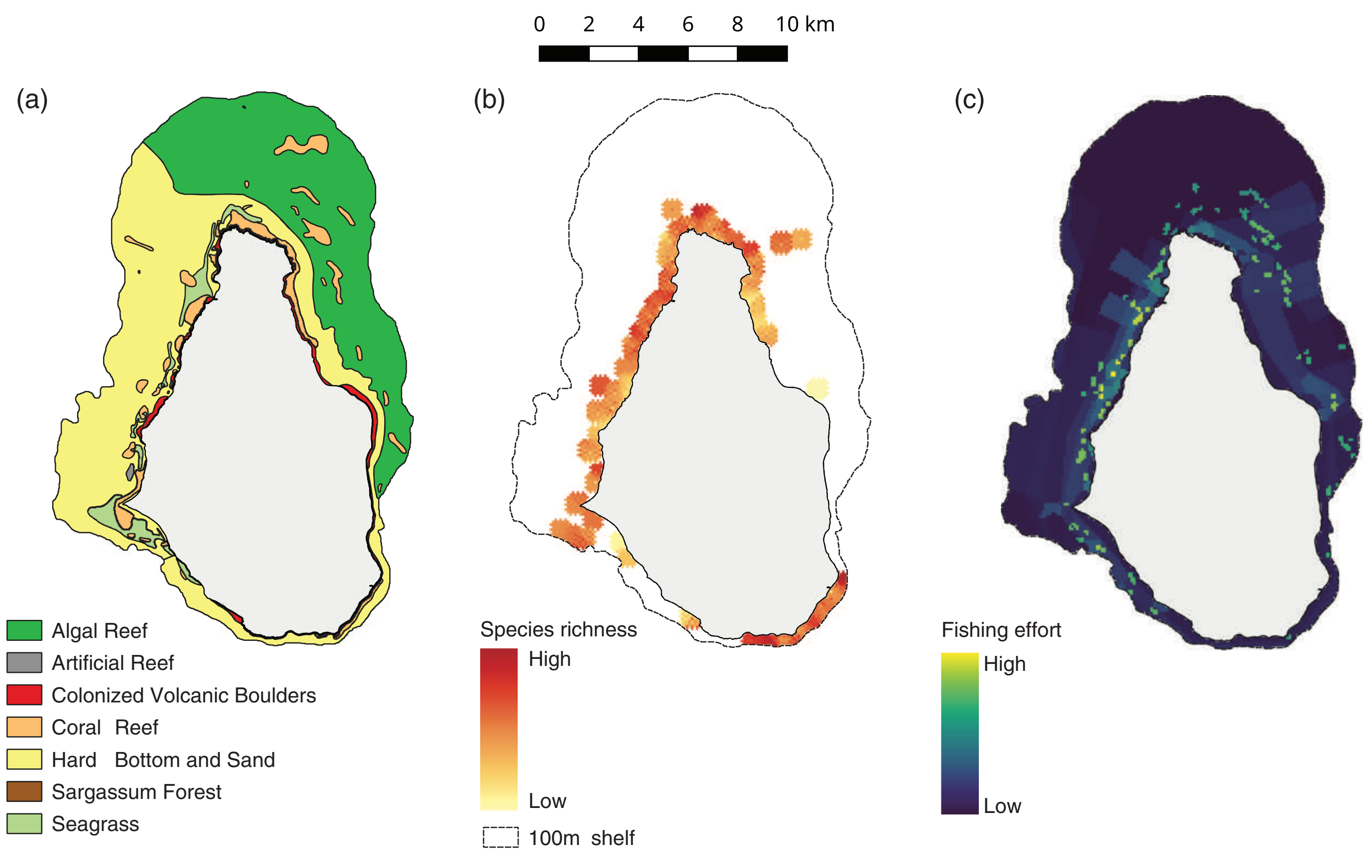

FIGURE 3 Maps of inputs used for prioritizr: (a) Benthic habitat map for 0 – 100 m depth developed during scientific surveys completed in 2014 – 2015; (b) Summed coral and fish species richness from reef survey data, interpolated to 500m radius around points and constrained to limits of 100m shelf; (c) Fishing effort, combining data from surveys with fishers and GPS locations of fishing traps

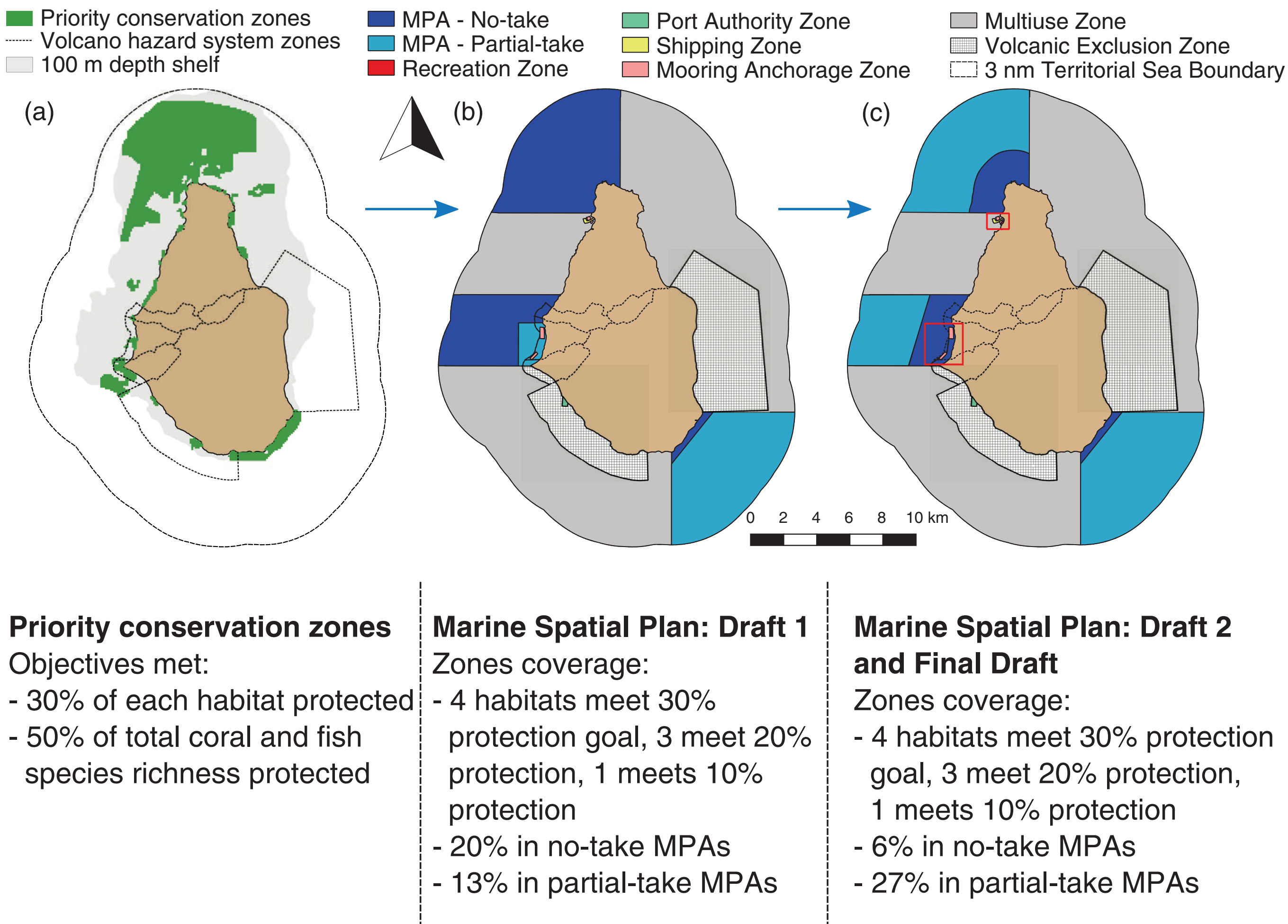

FIGURE 4 Maps showing the progression of Montserrat's marine spatial plan: (a) priority conservation zones selected using prioritizr; (b) marine spatial plan agreed upon by the Committee for first public consultation; (c) marine spatial plan agreed upon by the Committee for the second round of public consultation and the plan pending review by cabinet. For close-up of red highlighted areas, see Figure 5

4. Cost/impact—we developed a proxy for spatial fishing effort (Figure 3c), to minimize the impact of the conservation areas on fishing activities. A combination of two data layers was used to form the fishing effort proxy: (a) spatial survey data from fishers ($n = 55$) recorded using SeaSketch, as a relative measure of fishing pressure; and (b) fish trap GPS points recorded during the scientific assessment (Estep et al., 2018). The fish trap locations were buffered to 100 m to account for movement of the traps while underwater and horizontal distance between buoy and actual trap location. The two layers were rescaled 0–1 and summed without weighting.

The targets for the selection of priority conservation zones can be summarized as protecting 30% of each habitat type and 50% of summed coral and fish species richness, while minimizing the overlap with fishing areas. Further to these parameters, prioritizr has boundary penalties that can be used to favor zones that are clumped together. To set the boundary penalties, we ran the optimization using multiple scenarios, incrementing the boundary penalty in each. For the final result (Figure 4a), we used a penalty of 0.001, which provided a balance between the resulting zones being excessively fragmented versus forced into a single contiguous zone. One further parameter, the edge factor, was set at 0.5 to ensure that planning units along the coast were not unfairly penalized due to the absence of neighboring planning units.

7 | ZONING PROCESS AND SELECTION OF FINAL PLAN

7.1 | Marine spatial plan: Draft 1

The Committee used the map of priority conservation zones (Figure 4a) to help guide their placement of MPAs in the first draft marine spatial plan (Figure 4b). Presenting multiple zoning scenarios could have shown different possibilities for protection targets, number of zones, etc. (see Figure S3). However, the Committee asked for a single scientific recommendation to ease interpretation and avoid confusion, therefore only one map of priority conservation zones was presented (Figure 4a). As the zones were fragmented, the Committee created contiguous zones with straight boundaries that would facilitate enforcement and compliance. The priority conservation zones were all within the 100 m shelf because that was the geographical limit of the data used to create the zones. However, the Committee was tasked with zoning Montserrat's entire territorial sea, which extends out to the 3 nautical mile (nm) limit, and therefore they extended the boundaries of their proposed MPAs out to the 3 nm limit. They also chose to make parts of the MPAs partial-take (i.e., some forms of fishing allowed) because there were concerns that prohibiting all fishing in all proposed MPAs would be too restrictive for fishers. Specifically, the proposed partial-take MPA in the west bans fish traps only, ensuring that nearshore seine netting, spearfishing, and hook and line fishing can continue, and the partial-take MPA in the south-east bans fish traps and spear-fishing, allowing hook and line fishing, and trolling (i.e., fishing with a baited hook and line towed behind a moving boat) for coastal pelagic species (Figure 4b).

Apart from MPAs, the Committee also wanted to create zones for specific activities such as shipping and mooring. Zoning of Little Bay was a priority, as this is the most heavily used coastal area around the island due to the presence of the island's only port facilities. A shipping zone and two mooring anchorage zones were proposed in Little Bay, informed by the representative from the Port Authority with input from the rest of the Committee (Figure 5a). Two further mooring zones at Old Road Bay and Fox's Bay were proposed to provide designated anchorages for visiting yachts that already moored in those areas (Figure 5b). Compared to the decision process for the MPAs, the Committee reached consensus on these "utility" zones relatively quickly.

Based on the Committee's discussions and initial zoning ideas, the Science Advisory Team developed three zoning plans representing opinions within the Committee (Figure S4), and presented these plans to the Committee along with information on which conservation objectives they met. The Committee voted on these plans, and the chosen plan (Figure 4b) was disseminated to solicit feedback from key stakeholder groups (fishers, NGOs, boaters, and the private sector), the general public, and government departments. The public consultation was accompanied by an education and outreach campaign to raise awareness of the MSP process, strengthen knowledge of MSP and the importance of the ocean environment, and encourage participation. Feedback was gathered and synthesized by the Science Advisory Team and presented to the Committee.

7.2 | Marine spatial plan: Draft 2

The Committee modified the zoning plan based on the feedback from the first round of public consultation. The most visible change was the conversion of the offshore

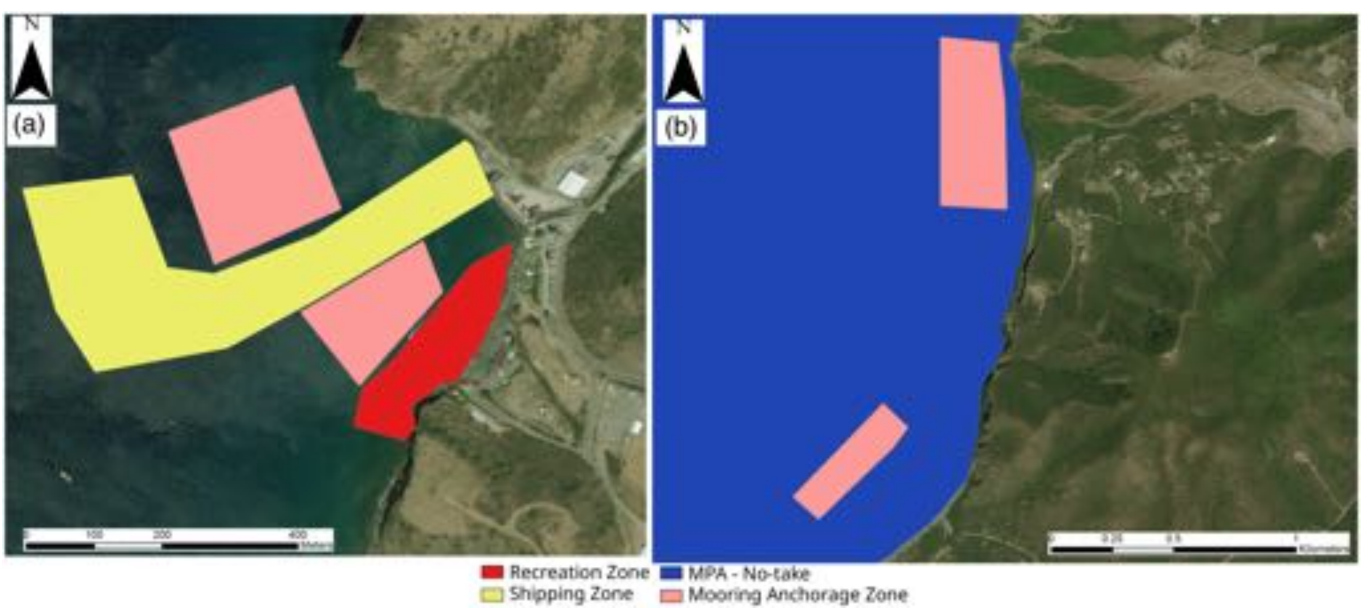

FIGURE 5 Close-up of (a) zones in Little Bay, and (b) mooring zones at Old Road Bay and Fox's Bay. See Figure 4 for location of these areas in the context of the whole island

sections of no-take marine reserves into partial-take MPAs (Figure 4c), which was primarily due to concerns about putting large areas off limits to trolling. The partial-take zones in the west and north-west would only allow trolling and the partial-take zone in the southeast would allow both trolling and hook and line fishing. These changes reduced the total no-take area, but trolling in Montserrat principally targets pelagic species, such as wahoo and tunas, and both trolling and hook and line fishing have little impact on bottom habitat and benthic species like corals. The Committee also decided to add a recreation zone in front of the beaches at Little Bay and Carr's Bay, with the intention of reducing overlap between recreational activities (e.g., diving, snorkeling, swimming, kayaking), and fishing and shipping (Figure 5a).

7.3 | Marine spatial plan: Final draft

A second, final round of public consultation was conducted on the modified zoning plan (Figure 4c). This consultation involved: (a) a brief five-question online survey; (b) two stakeholder meetings with civil society and fishers, and (c) meetings with government officials. The surveys were conducted directly in the field using a mobile phone, and indirectly via email and Facebook (total of 43 responses registered). The Science Advisory Team summarized public feedback and highlighted recommendations that were presented back to the Committee. As per the process following the first round of public consultation, the Committee discussed zoning options and the Science Advisory Team helped them develop three plans on which they voted. Votes were split almost equally, therefore all three plans were presented to MATLHE for a final decision. To aid the Ministry in making a decision, the Minister and Permanent Secretary attended a final meeting of the Committee where the Science Advisory Team summarized which objectives the three proposed plans met and the Committee members expressed their views. The final plan selected by MATLHE (Figure 4c) creates MPAs that cover 33% of Montserrat's Territorial Sea: 27% in partial-take zones, 6% in no-take zones, and 0.2% in other zone types combined (4 mooring anchorage zones, 1 recreation zone, 1 shipping zone, and 1 Port Authority zone).

8 | LESSONS LEARNED

Despite the increasing use of MSP in small island nations, there are few examples of how science can contribute to the decision-making process in practice, particularly in the Caribbean (McConney & Chuenpagdee, 2011; Pomeroy et al., 2014). Montserrat's draft marine spatial plan would zone the Territorial Sea (3 nautical mile limit), placing 27% in partial-take zones, 6% in no-take zones, 0.2% in utility zones (e.g., shipping, mooring, and anchorage zones), with the remaining area either being multi-use (i.e., open to all activities; 52%) or restricted access due to the volcanic exclusion zone (15%). With the aim of informing MSP projects on other small islands, and MSP more generally, we draw some general lessons regarding scientific support for MSP:

1. *Provide on-site scientific support and guidance throughout the MSP process*: Scientific data and input is a vital part of the MSP process (Lombard et al., 2019; Stamoulis & Delevaux, 2015). In Montserrat, the Science Advisory Team provided scientific and technical support throughout the MSP process, including guidance on potential objectives for MSP, data synthesis and presentation, and facilitation of the participatory zoning process. Although much of the scientific information relevant to MSP was available online through the SeaSketch platform, we found that presentations and discussions were essential to help the Committee interpret and apply the information. Providing access to scientific information (e.g., via a web-based mapping and data platform) can be useful for transparency and encouraging public participation, but pairing such efforts with in-person communication and engagement can more effectively reach nontechnical stakeholders.
2. *Set clear objectives*: Establishing specific objectives for the planning process is fundamental and is most useful when done early in the process (Day et al., 2019; Ehler & Douvere, 2009). Our experience was that overarching goals such as "30% protection of an area" provide a useful starting point, but these must be made more specific, for example, "30% of each habitat type will be placed in a network of no-take marine reserves". The process of setting objectives should involve decision makers, advisory bodies (in our case the Committee), and relevant stakeholders, with scientific input guiding the selection of objectives that are viable given the data constraints and determining how to operationalize the objectives. Clear and specific objectives from the outset of MSP in Montserrat would have made the spatial prioritization process easier, because these could have been included directly in the prioritization. As it was, the Science Advisory Team had to take general goals, for example, protect biodiversity, and convert them into specific objectives in order to identify high priority conservation areas.

3. *Work within data limitations*: Small islands, particularly developing nations, may lack suitable data to use in MSP (Pomeroy et al., 2014), and global or regional datasets may not have sufficient spatial resolution to be useful for planning in these cases. However, creative use of existing data or collection of simple proxy data can still be helpful. For example, in Montserrat we created a reasonable proxy of fishing effort using fisher survey data (self-reporting of most important fishing areas) and observed locations of fish traps in the absence of vessel monitoring system (VMS) and automatic identification system (AIS) data now commonly used to measure fishing effort in more data-rich contexts (Kroodsma et al., 2018). Similarly, we interpolated reef survey data to create a layer of reef species richness because the data for other methods, such as species distribution modeling, were not available. Both of these examples show how available data can be used effectively where ideal data are unavailable.
4. *Take advantage of decision support tools*: Most MSP projects use one or more decision support tools (Pınarbaşı et al., 2017). The two principle ones we used, SeaSketch and prioritizr, facilitated stakeholder engagement and the use of scientific information in decision-making, though many other tools are available to assist MSP projects (Pınarbaşı et al., 2017; Stamoulis & Delevaux, 2015). SeaSketch was used to collect new data, such as spatial ocean use data from fishers and divers (Figure S1), as well as to compile and display pre-existing data in a central platform. It was well-suited to the small-island context as surveys could be completed online or at in-person meetings with the Science Advisory Team, and a high proportion of the relatively small number of stakeholders could be reached. SeaSketch can be even more useful in settings where a high proportion of stakeholders have internet access and a high level of computer literacy. It was also used extensively as a planning tool, enabling the Committee and other stakeholders to sketch zoning ideas that could be easily consulted in the decision-making process. The spatial prioritization package, prioritizr, was suitable for MSP in Montserrat as it does not have high data requirements so we could use the available data as inputs. Prioritizr is implemented through the R coding environment (R Core Team, 2018), which is free and open-source, making it a viable tool for use in MSP when budgets are tight. However, obtaining useful output from such analysis is dependent on having data that represents the objectives and impacts relevant to MSP. In our case, the lack of data beyond the 100 m depth contour constrained the spatial extent of the prioritization analysis.
5. *Make data accessible*: MSP typically attempts to compile all existing spatial data relevant to the marine environment, and may also include the collection of new data, such as the scientific assessment data in our case. Making sure that these data are easily accessible by all stakeholders and decision-makers improves transparency and informed decision-making. We made all spatial data used in MSP publicly accessible via the SeaSketch website (montserrat.seasketch.org). Synthesized versions of other data were made available in accessible formats, such as reports provided both in print and online, and copies of all raw data were provided to the relevant government departments to ensure local ownership of data.

9 | DISCUSSION

Despite Montserrat's small population and relatively low intensity use of its ocean space, MSP was by no means straightforward. Representatives of the fishing community generally pushed for decreases in the size of the no-take area, while tourism operators were vocal about protection for the reef areas around the island. One objection from fishers was that the proxy fishing effort data (fishers' self-reporting of most important fishing areas combined with observed locations of fish traps) did not show some important fishing areas. These data did have weaknesses, for example, the fish trap observations were all from October 2015 and because some traps are moved seasonally, some fishing locations were likely not recorded. Additionally, despite best efforts to survey as many fishers' as possible, some fishers may have been missed, and similarly some trap locations may not have been observed due to missing buoys, rough seas, or the buoys being outside the area surveyed. Direct measurement of fishing effort would have been preferable, but artisanal fishing boats such as those in Montserrat are rarely fitted with AIS or any other form of vessel tracking; typically only industrial fishing effort is measured in this way (Kroodsma et al., 2018). Small, affordable, and robust vessel tracking systems using mobile phone signals and GPS are starting to be deployed in some small-scale fisheries (e.g., Metcalfe et al., 2017; www.pelagicdata.com) and present a useful option for obtaining data on the spatial distribution of fishing for artisanal fisheries.

Another shortcoming of the data we had available was a lack of information beyond the 100 m depth contour. As our focus was on nearshore coral reef and seagrass habitats, data for areas further offshore was not a priority. Furthermore, collection of habitat and species data in deeper depths is expensive, time consuming, and requires specialized equipment (Brown, Smith, Lawton, &

Anderson, 2011). This cost has to be weighed against the value of the data for the planning process. One option to avoid the time and expense of new data collection is to use existing global or regional datasets, such as Aquamaps which provides global species distribution maps for fishes, marine mammals and invertebrates (Kaschner et al., 2016). However, this would not have been suitable for Montserrat as the resolution of the data (0.5° cells) is too coarse, so that only one cell of data covers all of Montserrat's Territorial Sea. Environmental data, such as geomorphological features (e.g., seamount and knolls), water temperature, currents, and salinity, can be used as surrogates for species and habitat diversity (Ceccarelli et al., 2018; McArthur et al., 2010), though again, spatial resolution of global datasets may be insufficient for zoning of small areas.

Including the impacts of climate change in the planning process could have resulted in a more climate resilient zoning plan, but the same problems of obtaining data at resolutions useful for small islands, as previously discussed, would have made this difficult. Progress is being made at producing higher resolution climate change predictions that are useful for conservation planning at the scale of small islands, such as identifying reefs that are expected to be less vulnerable to coral bleaching and so could be prioritized for protection (Chollett & Mumby, 2013; van Hooidonk, Maynard, Liu, & Lee, 2015). Although we did not explicitly include climate change in the MSP process, no-take areas are one way that climate change impacts can be partially mitigated (Roberts et al., 2017) and the areas drafted fulfill some of the recommendations for producing climate resilient MPAs (McLeod, Salm, Green, & Almany, 2009). Given the uncertainty of the specific, local impacts of climate change, adopting an adaptive management plan is advisable, though this should include safeguards to avoid reductions in protection without scientific support.

Montserrat's marine environment has been severely impacted by ash and pyroclastic flows from the Soufrière Hills Volcano, and this impact was indirectly included in the zoning process because the existing volcanic exclusion zones were part of the marine spatial plans. Integrating land-sea interactions into MSP is still a relatively new area of research and practice (Álvarez-Romero et al., 2011; Álvarez-Romero et al., 2018). It has considerable importance for small islands where sedimentation and pollution from coastal development, farming, and a lack of proper sewage systems can result in significant impacts on the marine environment (Amato, Bishop, Glenn, Dulai, & Smith, 2016; Risk, 2014). Montserrat is planning a port development at Little Bay, which could impact the nearshore environment, including the proposed recreation zone within the bay and the no-take areas that lie north and south of the bay. The draft marine spatial plan did not consider land use despite the fact that such practices could affect the ability of zones to meet their intended objectives, and although the development process for the port includes an Environmental and Social Impact Assessment, including this development in the zoning process would have been a more pro-active planning approach. Lack of consideration of land use is a common deficiency in marine zoning which integrated land-sea planning approaches can help resolve (Álvarez-Romero et al., 2011; Harris et al., 2019).

The priority conservation areas map, created using prioritizr, was an important input to MSP, used by the Committee to guide their decisions on where to site MPAs. We chose to target 30% of each habitat for inclusion in the conservation areas, which is consistent with global conservation targets (Dinerstein et al., 2019; World Parks Congress, 2014), but we acknowledge that this target might not be suitable in all cases. For example, where there is high fishing pressure, a larger protected area may be necessary to ensure species persistence and to maintain fisheries catches, whereas in areas with strong fisheries management and minimal habitat impacts, a much lower protection target might be sufficient. Ultimately protection targets may be decided more by politics than science (Campbell, Hagerman, & Gray, 2014), but the underlying goals they are trying to achieve, such as effective conservation of ecosystems and biodiversity, are difficult to operationalize and area targets are easy to measure and provide some assurance of meaningful conservation action when properly implemented (Dinerstein et al., 2019; Watson, Dudley, Segan, & Hockings, 2014). In our case, use of a different target is unlikely to have affected the final placement of no-take zones (Figure S3), which was heavily influenced by feedback from fishers, although it could have influenced the size or number of protected areas.

We only used the conservation planning package prioritizr once; to provide initial zoning guidance to the committee. Other MSP projects could improve on our approach by repeating the prioritization as decisions are made regarding zoning. For example, if it is decided that certain areas should definitely be in an MPA, these areas could be "locked-in" as protected in prioritizr, and the prioritization rerun to see how the priority conservation areas map changes (see Figure S5 for an example). Another improvement to our approach would be the use of the management zones functionality in prioritizr (added after our use of prioritizr), which allows for spatial prioritization for no-take and partial-take zones separately. Since the Committee chose to create some partial-take zones, including that option in the prioritization would have allowed us to give more relevant advice and more flexible options for the MPAs.

The scientific input to Montserrat's MSP process provided guidance to the Committee and the government, and underpinned many of the zoning decisions made, despite some of the shortcomings of the data. Montserrat has features that are similar to many other small island nations, such as a large ocean area relative to land mass, small-scale fisheries and tourism industries, and limited local capacity for MSP. The lessons learned during our experience of MSP may provide guidance for other data-limited, small islands undertaking MSP, as well as other MSP projects more broadly.

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AUTHOR CONTRIBUTIONS

All authors conceptualized this work and took part in the MSP process. J. F. produced all of the R code and Figures. J. F. wrote the manuscript with input from all authors.

DATA AVAILABILITY STATEMENT

Data and R code to reproduce the prioritization are available on GitHub: https://github.com/jflowernet/Montserrat_MSP_prioritization.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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