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# Science Summary in Support of Manatee Protection Area (MPA) Design in Puerto Rico


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# Science Summary in Support of Manatee Protection Area (MPA) Design in Puerto Rico

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With results of an independently funded model component

# Sheltered Coastal Waters of Puerto Rico

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## 1. ABSTRACT

The Antillean manatee (*Trichechus manatus manatus*), a subspecies of the West Indian manatee, is listed as endangered by the U.S. Department of Interior. In accordance with its listing, the U.S. Fish and Wildlife Service's Caribbean Field Office (USFWS) is mandated to create one or more Manatee Protection Areas (MPAs) for Puerto Rico. Designation of these areas must comply with the legal definition of an MPA's purpose: to prevent or reduce take of manatees (CFR 50: 44 FR 60964, Oct. 22, 1979). To meet this goal, we pursued two objectives: 1) identify areas that include the specific ecological attributes necessary to support manatee populations, and 2) identify areas where take can be reduced through approved MPA regulatory frameworks. We achieved these objectives through literature review, expert elicitation, and geospatial modeling. This report delivers to USFWS a set of nine potential MPA regions. These regions represent the spatial realization of experts' hypotheses regarding manatee requirements and threats and the potential to implement MPA strategies (e.g., watercraft access, speed regulations, signage, and boater education). The nine regions are compared based on a number of factors, including their potential to reduce take, quality of the habitat encompassed, and total area. These maps and statistics serve as suitable starting points to select one or more MPA sites, but we recommend that the mapped attributes and threats (i.e., boating activity) of MPAs be ground-truthed to visually confirm the local presence of resources, threats, and manatees before any area is selected. Once established, the effectiveness of MPAs can be monitored and updated through processes of adaptive monitoring and management. Aerial surveys, radio tracking studies, and public surveys are all valuable tools to assess the success of an MPA. Establishing MPAs is a management action that, integrated within the species Recovery Plan, should enhance the conservation of manatees.

## 2. INTRODUCTION

The Antillean manatee (*Trichechus manatus manatus*, hereafter manatee), inhabiting Puerto Rico's coastal waters, is a subspecies of the endangered West Indian manatee (Federal Register, July 22, 1985. Vol. 50(140):29900-29909). Habitat loss and human-induced mortality are considered important factors leading to this species' precarious status. A Recovery Plan for the Puerto Rico population of the West Indian (Antillean) manatee was released in 1986 and drew from studies in Florida to characterize the natural history of the species in Puerto Rico (USFWS 1986; hereafter: original Recovery Plan). Since listing of the manatee and the release of the original Recovery Plan, the U.S. Fish and Wildlife Service (USFWS) and the Puerto Rico Department of Natural and Environmental Resources (PRDNER) have implemented various recovery activities primarily focused on environmental education, regulatory efforts, habitat mapping, and monitoring (USFWS 2007). Aerial surveys conducted at various intervals since the 1970s have helped ascertain manatee distribution patterns (Powell et al. 1981; Rathbun et al. 1985; Mignucci-Giannoni et al. 2006). Past population estimates (USFWS 2009) did not account for low detectability of manatees, so likely underestimated the true number of individuals. New survey methods in development provide a preliminary detection adjusted estimated population size of 342 to 802 individuals with a 95% credible interval (M. Krachey, North Carolina State University, personal communication).

To improve the manatees' status, the original Recovery Plan called for the "identification and management of habitat important to the species' survival" and management plans for these habitats that would address "boat densities, the need for sanctuary areas, boat speed regulatory zones, information and education, and data needs" (USFWS 1986). The establishment of manatee protection areas (MPA) was also one of the core recommendations made by the U.S. Fish and Wildlife Service 5-year review (USFWS 2007). MPAs are implemented to prevent or reduce take of manatees by managing watercraft access to, and activity in, manatee habitat (CFR 50: 44 FR 60964, Oct. 22, 1979).

MPAs are one strategy within the broader set of conservation and management tools that will foster the persistence of the species in the Caribbean through protection of habitat and regulation of human activities (USFWS, in review; hereafter: revised Recovery Plan). An effective MPA regulates human activity to reduce the overall take (including harassment) of manatees in Puerto Rico by preventing the take of one or more manatees within MPA boundaries. As increased public awareness has decreased hunting incidents, watercraft collisions are now considered the primary documented source of human-caused manatee mortality in Puerto Rico (Mignucci-Giannoni et al. 2000) and thus watercraft threat are a focus of MPA regulations. The design of an effective MPA, however, also requires knowledge of manatee resource use patterns and the relationship between resource use and the current threats to manatees and their habitat. Potentially limiting resources include seagrass, freshwater and sheltered waters (i.e., shallow water protected from wave action) (Powell et al. 1981; Lefebvre et al. 2000). The quality of seagrass beds, the primary feeding habitat of manatees in Puerto Rico (Mignucci-Giannoni and Beck 1998; Lefebvre et al. 2000), could be impacted by sedimentation (NOAA 2004) and other land-based sources of pollution, in addition to damage by propeller scarring (Smith 1993; PRDNER 2010a). Water quality could also be impacted by pollution or flow could be reduced through agricultural and industrial demands.

## 2.1 Project Objectives and General Approach

The overall goal of this project was to assist the USFWS to address a core recommendation made in the USFWS 5-year review (USFWS 2007) by identifying and providing the scientific basis to propose MPAs in accordance with federal regulations (CFR 50: 44 FR 60964, Oct. 22, 1979). To support the USFWS in their mission to provide one or more MPAs that satisfy the landscape and habitat requirements of manatees while also reducing take, we pursued two primary project objectives: (1) identify areas that include the specific ecological attributes necessary to support manatee populations, and (2) identify areas where take could be reduced through approved MPA regulatory frameworks. We achieved these objectives through literature review, expert elicitation, and geospatial modeling. Areas that ranked high under both objectives were identified as candidate regions for establishment of an MPA, pending field site assessments to validate the results and agency evaluation of site feasibility.

To ensure a transparent MPA design and evaluation process, we followed established conservation planning strategies. We drew primarily from procedures outlined in the Open Standards for the Practice of Conservation (Conservation Measures Partnership 2007), but also from closely related methods of Structured Decision Making (SDM) (Gregory and Keeney 2002). We used these structured expert elicitation techniques to provide consistent terminology, define consensus conservation objectives, identify key attributes of the ecological system, model pathways by which conservation targets are threatened, and characterize the potential impact of MPAs as a conservation strategy. Knowledge of manatee ecology and biology gathered through literature review and two expert workshops was organized using the Open Standards conservation planning software, Miradi (Version 3.2.2). We then modeled the spatial distribution of the required resources and threats to identify regions most suitable for MPA implementation. The project work flow is illustrated in Figure 1. Detailed methods and results for each step are provided in the following sections.

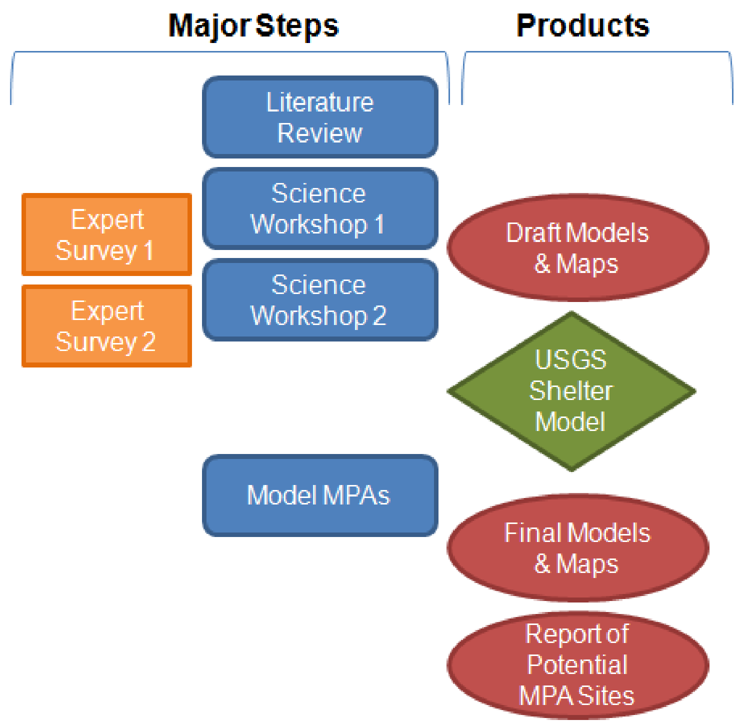


Figure 1. Work flow depicting major steps (blue and orange squares) to gather available data and elicit expert knowledge of manatees in Puerto Rico for the purposes of supporting USFWS Manatee Protected Area site selection and design. Data products and recommendations reflecting best available science appear on right (red ovals and green diamond). The majority of the modeling used available national and territorial spatial data, but the shelter model is a new data product created for this project.

Creating predictive models encompasses multiple steps. For the purposes of this document, we use the term "model" to refer to the outputs derived from the process of conceptualizing expert hypotheses, creating representative equations of those hypotheses, and applying these equations within a geospatial analysis to predict specific resources occurrences that may influence the distribution of manatees in the coastal waters of Puerto Rico (Guisan and Zimmermann 2000). While we are unable to validate the models given the absence of independent empirical data, we did confirm (1) that the model components and final output did accurately reflect experts' hypotheses, and (2) that regions predicted to have high resource value and high threat value did correspond to regions recognized to have manatees and watercraft mortality, respectively.

In addition to meeting the core recommendations of the 5-year review (USFWS 2007), we also operated under the guidance of USFWS Strategic Habitat Conservation principles (USFWS 2006). Strategic Habitat Conservation emphasizes the need for science-based, landscape-scale, transparent conservation planning, design, implementation, and monitoring as an adaptive management process. Conservation actions, always implemented in the presence of imperfect information, are recognized as the realization of a set of hypotheses about how the system is threatened and how perceived threats might be reduced or mitigated through management actions. Therefore, after gathering and processing available data and expert knowledge of manatee requirements and threats, we represent this information as a set of testable hypotheses. These hypotheses define the expected, untested relationships between empirical observations (e.g., watercraft threat) and geospatial data that serve as proxy to predict regions of high versus low threat (e.g., density of boating infrastructure such as buoys and ramps). The valuation of the marine landscape surrounding Puerto Rico for the potential contribution to MPA objectives rests upon these hypotheses.

The product delivered to USFWS is a set of nine potential MPA regions. The nine regions are compared across a number of factors, including their potential to reduce take, the quantity or quality of the habitat encompassed, and the total area encompassed. By this process, our report provides USFWS with documentation of the available data and knowledge, the MPA valuation process, the strengths and weaknesses of the nine potential MPA regions, and the hypotheses and assumptions upon which the analysis rests. We do not provide detailed site level recommendations (e.g. coordinates for the locations of buoys or boundaries), as the accuracy and precision of the available spatial data do not support specific zoning recommendations. However, we do provide a detailed summary of available knowledge and research conducted within each region, which would provide the starting point for such decisions. We also identify potential management and policy actions that were identified and discussed by experts.

## 3. METHODS

### 3.1 Literature Review

We performed a literature review to identify key ecological attributes necessary to sustain manatee populations, determine natural and anthropogenic threats to manatees, and identify potential strategies to protect resources or reduce threats. Although manatees generally have been well-studied, particularly in Florida, there is less literature specific to manatees in Puerto Rico. We began by reviewing the literature cited and summarized in the original Recovery Plan. We then searched for research journals and government reports published since the original Recovery Plan's release in 1986 to July 2012. In addition to defining the current state of knowledge, our review results guided the development of elicitation strategies for the expert workshops and the collection of spatial data resources.

### 3.2 Expert Knowledge Elicitation and Modeling

Expert input was necessary to address knowledge gaps in the published literature and to establish consensus on project objectives. The USFWS identified and invited experts from Puerto Rico and Florida. Experts were identified as those with direct knowledge of manatee in Puerto Rico, achieved through participation in research or population monitoring (e.g., aerial surveys and strandings), though manatees were not the current primary focus of all experts' work. In two workshops and two surveys we elicited these experts' knowledge of manatees and their habitat (Appendices 1 and 2). Workshops used a mix of elicitation methods including full group discussion, small group brainstorming sessions, and individual surveys or votes. Group methods were used when we needed consensus definitions or decisions and when generating lists of possible manatee threats and key ecological attributes. We used individual methods when eliciting rank (e.g., relative threat level) or numeric (e.g., healthy population size) estimates. Variance among individuals' responses could then be evaluated as reflecting knowledge uncertainty or natural variability among the regions and periods of individuals' observations.

In addition to defining project objectives and geographic bounds, the first workshop identified ecological requirements of manatees, threats to manatee populations, and possible actions to mitigate these threats. At the second workshop, experts reconvened to review the compiled results of the first workshop and the draft spatial models of manatee key ecological attributes and threats. Experts also provided input on how the spatial data layers representing resources and threats would be individually valued and then combined to generate a single data layer depicting potential MPA value. The surveys supplemented the workshop data by addressing specific points of confusion or dissension, or posing questions that could not be completed within the workshop time.

### 3.2.1 Open Standards Elicitation Framework

Throughout this document, unless otherwise noted, we employ the terminology of the Open Standards method (Table 1). The Open Standards elicitation and conservation planning framework was developed by the Conservation Measures Partnership, a collaboration among international land conservancies and researchers dedicated to understanding how to improve the practice of conservation (Margoluis et al. 2009). This framework, rooted in adaptive management, provides a multi-step guide to conceptually organize conservation projects in a manner that enhances the rigor and transparency of expert-knowledge based plans. Following this method, we can define explicit links between planned conservation activities to outcomes as well as indicators to measure success. Specifically, we used the Open Standards method to develop the elicitation questions, analyze expert responses, create a conceptual diagram, characterize and rank threats to manatees and their habitat, and create results chains for MPAs as a conservation strategy. The knowledge gathered through the Open Standards procedure applied to all aspects of manatee ecology and biology in Puerto Rico including their key ecological attributes, as the data were gathered for application both within the revised Recovery Plan for the PR Antillean manatee population and this document. This strategy of capturing information pertaining to the biology and ecology of the manatee ensured MPA recommendations grew from and maintained strong coordination with the revised Recovery Plan.

Table 1. Common terms and their definitions as used within the Open Standards for the Practice of Conservation, the associated Miradi software, and this report unless otherwise noted.

| Term | Open Standards Definition |
|---|---|
| Scope | • the thematic focus or geographic area of a project in which to concentrate efforts. |
| Vision | • the desired state or condition meant to be achieved by a conservation action and, which if achieved, would also signify success |
| Conservation targets | • specific species, ecological systems/habitats, or ecological processes around which a project is focused |
| Threats | • an anthropogenic activity that may cause the destruction, degradation, and/or impairment of biodiversity and natural processes |
| Opportunities | • factors which can both alleviate a threat or be an indirect threat depending on the context |
| Status assessment | • the assessment of a condition or status of a particular conservation entity (e.g., species, population, or ecosystem) |
| Key ecological attributes | • the biological characteristics of or elements required by a target central to its success |
| Conceptual diagram | • a network representation of causal relationships between targets, key ecological attributes, threats, and opportunities |
| Results chain | • a pathway from action to target detailing expected intermediate and final outcomes with timeline and measures of success |

We applied the Open Standards through the software program Miradi. Miradi is a tool developed to facilitate the adaptive management process outlined in the Open Standards framework. Miradi guides the design of conceptual diagrams and generates tabular summaries, which together illustrate relationships between targets, direct threats, indirect threats, and strategies (Margoluis et al. 2009; Conservation Measures Partnership 2007). Developing a conceptual model is a key step in building a common understanding of the project context and translating management assumptions into explicit testable hypotheses.

We adapted the framework to suit our specific project goals and objectives. Typically, an Open Standards project focuses significant effort to elicit and reach consensus regarding scope, vision, targets, and objectives that represent the full suite of biodiversity of a given area or site. However, this project's objectives had already been clearly defined in the original Recovery Plan and the endangered species legislation: identify potential MPAs for the benefit of the species by reducing take and protecting habitat encompassing the ecological attributes necessary to support the manatee population of Puerto Rico. Our primary effort therefore focused on characterizing the key ecological attributes, threats, and opportunities relevant to manatee conservation in Puerto Rico. We then narrowed this broad field of knowledge down to those specific elements relevant to the successful implementation of an MPA.

Another major adaptation of the Open Standards approach resulted from our need to produce spatially-explicit predictive models. The Open Standards and associated Miradi software elicit qualitative, aspatial information. To spatially model the potential MPA value of Puerto Rico's coastal waters, we required quantitative, spatial information for the key ecological attributes and threats relevant to the MPA results chains. Thus, for each MPA attribute and threat, we elicited a preferred metric to measure (e.g., seagrass habitat could be represented as the presence/absence, diversity, or percent cover of seagrass within a given area) and then elicited the hypothesized quantitative relationship between the variable and manatee use (e.g., suitability).

For the purposes of this document, we describe using the Open Standards framework as a method to guide expert elicitation and capture knowledge as it relates to predicting potential MPA regions. However, it is important to note that the information regarding MPAs was elicited in the broader context of eliciting knowledge of all threats and all possible conservation strategies for inclusion in the revised Recovery Plan. The revised Recovery Plan addresses many aspects of manatee heath and habitat threats that cannot be effectively managed through an MPA. Furthermore, the revised Recovery Plan outlines how MPAs and complementary management actions can be implemented, monitored, and improved under adaptive management principles.

### 3.2.2 Expert Workshop 1: Orientation, Conceptual Model, and Spatial Hypotheses

The objective of the first two-day workshop was to create the conceptual diagram that would guide our data collection and model development and, ultimately, define the role of MPAs within the broader framework of manatee conservation. Invitations were sent to individuals based on expertise in manatee ecology and biology in coastal Puerto Rico. We identified experts through peer recommendation, publication history, and past involvement in local research projects. Discussion comments were captured by a note taker and also via photographs of discussion points noted on a white board and flip chart.

The first expert elicitation workshop commenced with a broad overview of the Open Standards framework, defining terminology, and demonstrating examples of conceptual models.

With all experts together, we then elicited the foundation components that would set the geographic and thematic boundaries of our research efforts as well as the USFWS manatee conservation efforts more generally in Puerto Rico. These were the target, scope, and vision statements (see definitions, in Table 1). The primary target was predefined as the manatee, but we asked experts to debate the relative merits of naming seagrass as a secondary target versus a key ecological attribute. Experts agreed that the sole purpose of managing seagrass is to provide a foraging resource to manatees. Therefore, manatees remained the conservation target and seagrass a key ecological attribute rather than a primary subject of a proposed management action.

To define the scope and vision, we presented draft statements, which we had generated based on the original Recovery Plan, and asked experts to modify these statements. The scope and vision were broadly defined for manatee conservation generally within Puerto Rico. Later, in Workshop 2, experts defined additional scope and vision statements that would apply specifically to the MPA regions.

Once consensus target, scope, and objective statements had been defined, we asked experts to identify key ecological attributes and threats to manatees and their habitat (see definitions Table 1). Key ecological attributes identify and characterize the resources or conditions necessary to achieve and maintain a healthy target (TNC 2007b). Characteristics of key ecological attributes were elicited under three categories: quantity (number or area), condition (composition, structure, interactions), and landscape context (connectivity or other ecological processes) (TNC 2007b). Experts brainstormed in groups of five to six individuals and then reconvened to report their lists to the whole group. Again, for this initial workshop, we requested experts think generally, and in terms of manatee conservation in Puerto Rico, rather than restrict their discussion to MPA strategies alone. For each potential key ecological attribute identified through brainstorming (e.g., fresh water) the group discussed characteristics of the attribute that would potentially moderate its value (e.g., water source, quality, seasonality, abundance).

Due to time constraints, we did not ask experts to distinguish between direct and indirect threats, but we did ask experts to identify threats relevant to both manatee and seagrass. After organizing the listed threats into thematic groups, we guided discussion to capture why these variables were selected and how experts hypothesized that the listed threats related to one another. Experts were asked to consider, for each threat, whether it was specific to a subset of the scope (e.g., one specific geographic region), a subset of the population (e.g., juveniles versus adults), or a season of the year (e.g. wet versus dry). Then, for each threat, experts individually ranked the threat as a high, moderate, or low impact on manatee populations and indicated whether the threat could be mitigated through the establishment of an MPA or would require other intervention strategies.

Following the workshop, we used the discussion notes to categorize the threats as either indirect or direct. The Open Standards define a direct threat as an event causing a negative impact on the target and an indirect threat as a driver of that event. We created a conceptual diagram in Miradi to visually represent the relationship between targets, key ecological attributes, and threats, distinguishing between threats that could and could not be mitigated through creation of an MPA.

During the first workshop, we also elicited experts' knowledge of the manatee population status. We discussed the merits of, and concerns regarding, estimates produced through aerial survey and stranding data. Through small group brainstorming, followed by large group discussion, we discussed whether (and how) MPA implementation would impact manatee population status and then elicited experts' judgments regarding the metrics necessary to define and monitor population status.

### 3.2.3 Spatial Data Collection and Processing

Once we drafted the conceptual diagram, we gathered spatial data to represent the threats and key ecological attributes relevant to MPA site selection and expected success. Only existing digital data that covered the full project scope were eligible for inclusion in this project; some threats and resources could not be mapped due to the absence or limited extent of suitable data. We obtained spatially referenced data for three key ecological attributes: bathymetry (NOAA, No Date), seagrass (NOAA 2001), and freshwater access (USGS and USEPA 2005; J. Zegarra, USFWS, personal communication; M. Olaya, AAA, personal communication), and two threats: motorized watercraft (NOAA et al. 2005; PRDENR 2010) and sedimentation (NOAA 2004).

Spatial data were obtained in diverse formats, projections, resolutions, and extents. All data were transformed to raster format with a 30 m resolution (grid cell size) and reprojected to Puerto Rico State Plane (meters). Data outside the project scope were deleted. We used ArcGIS 9.3 for spatial data analysis. Metadata were produced for each data layer and delivered to the USFWS in accordance with federal data management standards (Appendix 3).

One key ecological attribute, sheltered waters, could not be represented with existing spatial data resources. Experts defined sheltered water as calm (wave height < 0.3 m), shallow (water depth < 3 m ) water and unanimously agreed that manatees prefer to rest in these areas. Sheltered waters have low wave energy, a function of prevailing wind speed and direction in relation to coastal land forms. As experts also agreed that a model ignoring the availability of shelter could not effectively compare the relative value of potential MPA sites, the USGS produced a wave energy model of Puerto Rican coastal waters (see Section 4.2.4.3). This model predicted wave energy for all shorelines within the project scope based on coastal bathymetry, wind speed, and wind direction. The resulting model was compared against the manatee telemetry data to rank bathymetry and then wave energy for the 90th percentile of manatee use. The intersection of these percentile layers defined the shelter preference of manatees.

The general procedure to translate resource or threat data into resource or threat value maps involved four steps. First, we considered whether value was influenced by water depth, and if so, we restricted our analysis to the resource (or threat) data within the identified depth zones. Second, we considered whether the value was simply a function of resource (or threat) presence, or if the abundance of resources (or threats) within a given area should be considered. If abundance was relevant, then we summed the number of resource (or threat) grid cells within a 5 km radius and then rescaled these data relative to the maximum to report value on a zero to one scale. This radius value was initially selected based on Powell's (1981) published statement that 85.8% of manatees detected during aerial surveys were within 5 km of a natural or artificial freshwater resource. This value was confirmed as reasonable based on preliminary telemetry data of manatees along the Puerto Rican coastline, which were presented and discussed at the second workshop (J. Reid, personal observation; Slone et al. 2006). Although some individuals were observed to frequent deeper waters (e.g., Vieques Sound) and swim long distances (e.g., Guanajibo to Guánica), local movement patterns were typically short distance movements between freshwater and seagrass resources (Slone et al. 2006). Third, we considered whether resource (or threat) quality would influence the value of an MPA region. If so, and if the relationship was a threshold response such that very low or very high values would be irrelevant to manatees, then we eliminated grid cells that fell outside the relevant range of values. If the response was expected to be continuous across the full range of values, then moving through the raster data grid cell by grid cell, we calculated the average data value within a 5 km radius focal area and rescaled these results relative to the maximum resource (or threat) value on a zero to one scale. Fourth, if both abundance and quality of resource (or threat) influenced the potential MPA value at a particular grid cell, we multiplied the results from steps two and three. Last, we combined the resource and threat values assuming a multiplicative effect (see Section 3.2.6); the lack of any one resource (seagrass, freshwater, or shelter) or the absence of threat (motorized watercraft) would reduce the potential MPA value to zero. By definition, an MPA must protect critical habitat while also mitigating threats or the potential occurrence of a threat.

#### 3.2.4 Surveys 1 and 2: Ranking Threats and Identifying Threat Mitigation Strategies

We conducted two surveys outside the workshops. One survey explored how threats could be reduced by MPA regulations and the other focused on ranking the direct threats. Threats are a critical factor affecting the selection, placement, and implementation of management strategies. By eliciting expert knowledge of threats and actions relevant to MPA implementation, Miradi calculates which threats present the highest assumed degree of impact on manatees and how MPAs can or cannot alleviate these threats.

The first survey was sent on October 14, 2010 to the participants of the first expert elicitation workshop (n = 14 of 21 experts responded). Its purpose was to define the expected outcomes of an MPA designation as a high reduction, a medium reduction, low reduction, or no effect for specific threats to seagrass habitat and manatees. Terms used within the survey were either defined within the MPA legislation (CRF 50:44 FR 60964, Oct. 22, 1979) or from information provided during the elicitations. This survey was conducted online and administered through Survey Monkey (http://www.surveymonkey.com/). Follow-up reminders were sent via email on October 18, 2010 and the survey closed October 22, 2010.

The second survey was also sent to all experts, including the one additional expert who joined at the second workshop (n = 11 of 22 experts responded). We sent this survey via email November 12, 2010. The questions were based on the Simple Threat Ranking method in Miradi, as developed by the Nature Conservancy (TNC) and the World Wildlife Federation (WWF 2007; Conservation Measures Partnership 2007; TNC 2007a). The survey listed direct threats and three categories on which the threat is ranked: percentage of population affected, severity or level of damage to manatees or seagrass, and the reversibility of the threat impact.

Expert responses to these criteria were analyzed within the Miradi software. However, given the small number of respondents and high variability among individual's scores of the various threats, Miradi could not generate the threat ranking report. In an effort to determine if variability resulted from confusion concerning the methodology or high uncertainty regarding the scope, severity, and irreversibility of threats, we facilitated a conference call on June 15, 2011 with five experts, one representing each of the participating agencies (USFWS, PRDNER, the Caribbean Stranding Network, and Bahía de Jobos National Estuarine Research Reserve). The conference call participants had attended previous workshops and were invited based on their experience with threats to manatees and their experience with carcass recovery and necropsies as well as manatee rescue, rehabilitation, and observation within the wild.

During the conference call we first summarized the ranking methodology to clarify definitions and expectations. Experts then discussed each threat in relation to the categories of evaluation (scope, severity, and irreversibility). Through the course of discussion, experts resolved points of confusion concerning survey language and unanimously agreed upon rankings, providing consensus as required by Miradi. Each direct threat ranking was also assessed through a review of relevant literature to identify any relevant information concerning applicable regulations of threats, observations of threat occurrence, and trends.

3.2.5 Expert Workshop 2: Conceptual Model, Resource and Threat Maps and MPA Value

The objectives of the second 2-day workshop were to: (1) review the draft conceptual model and accompanying spatial data layers, (2) review the results chains that connected MPA implementation to the manatee target, and then (3) to generate a consensus plan to combine the available information into a final set of MPA recommendations. Invitations were sent to all participants of the first workshop. Discussion comments were again captured by a note taker and also via photographs of the flip chart.

Participating experts received the conceptual model in both diagram and tabular format to facilitate communication and critical review of the hypothesized causal relationships among factors (e.g., direct and indirect threats) and the identification of pathways (results chains) by which MPAs could reduce take of manatees. Experts reviewed these materials first in small groups of four to five experts and then reported their observations and suggested changes to the full group for further discussion. The diagram and tables were adjusted based on this expert feedback. Discussion continued until all participants agreed that the conceptual diagram adequately represented their combined knowledge.

Next we presented the spatial data layers generated to depict key ecological attributes and threats. Data layers were presented one at a time, and experts considered whether the data chosen to depict a particular threat or key ecological attribute represented the best available data resource. This required them to evaluate whether the data were relevant and whether the data contained gaps that could be addressed by other known spatial data resources. Next, experts reviewed the procedure by which the data had been translated from discrete point or polygon data to continuous raster data representing resource value or threat risk. Last, experts reviewed the set of available spatial data layers to determine if they adequately captured the critical threats and key ecological attributes and recommended if any should be removed or added to the model that would identify potential MPA sites.

Finally, we described alternative methods to combine the threats and key ecological attribute layers to identify the top ranked sites for MPA placement. Experts had the opportunity to comment on this strategy and then to propose additional site selection criteria that would place different emphases on the various available data layers and/or consider socio-political, operational, or other potential site selection constraints.

### 3.2.6 Identification of Potential MPA Regions

Experts indicated that potential MPA sites must include access to all three manatee key ecological attributes: freshwater, seagrass, and sheltered waters. However, because the legislated objective of an MPA is to reduce take through the restriction or prohibition of certain watercraft activities, we identified areas where access to these critical resources spatially co-occurred with high watercraft threat. In the absence of data to define the relative importance of the three key ecological attributes, the attributes were assigned equal weight. The watercraft threat data were also weighted equally to the resource data. Thus, to calculate the potential MPA value of a site we calculated the geometric mean of the four MPA variables (three key ecological attributes and one threat):

$$\text{MPA Value} = (\text{Freshwater} * \text{Seagrass} * \text{Shelter} * \text{Watercraft})^{(1/4)}$$

Each variable was scaled relative to the maximum value for that variable within the project scope, such that values ranged from zero to one. Therefore, the MPA value also had a potential range of zero to one. If, at a grid cell, any one variable had a value of zero, the MPA value of that grid cell was also zero.

The identification of potential MPA sites required the aggregation of high-valued raster grid cells into regions of high potential MPA value. After first excluding all grid cells valued at zero, we identified all grid cells in the 90th percentile (the top 10% of values). These grid cells were grouped into regions using an eight-neighbor rule (grid cells were defined as neighboring if they shared an edge or a corner). This process was repeated for the 80th percentile (the top 20% of values) as a less conservative threshold for designating potential MPA regions. For both analyses, only regions larger than 1 $km^2$ were identified as potential MPA regions. One square kilometer is the approximate size of the smallest existing marine reserve within our project scope (Reserva Marina Tres Palmas de Rincón, 0.8 km2).

## 3.3 MPA Model Assessment

Assessment of the model assumptions, structure, and logical consistency was accomplished through three qualitative procedures: (1) expert review, (2) comparison against available manatee sightings data, and (3) comparison against available manatee mortality data. The expert review focused on the individual models for each key ecological attribute and watercraft threat. Experts were asked if the maps accurately represented their knowledge of the distribution of resources and threat within the scope. Areas with unexpectedly high or low results were highlighted and discussed with particular emphasis on whether they likely reflected ecological knowledge gaps or spatial data gaps. To confirm that manatees occur in the modeled potential MPA regions, we plotted all manatee sightings from aerial surveys (1984-2002; USFWS unpublished data) and assessed whether the model results matched the detection hotspots. To confirm that our model identified sites with potential to reduce watercraft threat, we compared locations of high value MPA regions against published overall carcass recovery hotspots (1864-1995; Mignucci-Giannoni et al. 2000 ) and watercraft mortality events (2000-2010; PRDENR, unpublished data).

# 4. RESULTS

## 4.1 Literature Review

The original Recovery Plan provides a detailed review of literature up to 1986, the date of the Plan's publication. We therefore focused our review efforts on Puerto Rican manatee research and reports published since release of the original Recovery Plan. The summary results presented here parallel the section headers in the original Recovery Plan and emphasize only those studies with information relevant to comparing potential MPA sites (e.g. key ecological attributes and threats). The full results of our literature review across all topics relevant to manatee recovery can be found in the revised Recovery Plan.

### 4.1.1 Distribution and Abundance

Recent island-wide aerial surveys to characterize manatee distribution patterns (1984 – 2002, USFWS unpublished data) generally confirm the observations of Powell (1981) and Rathbun et al. (1985); manatees are most frequently observed along the south-central and eastern coasts and not on the northwestern coast. Roosevelt Roads Naval Station (RRNS), the northwest coast of Vieques, Bahía de Jobos, and Guayanilla consistently presented a high number of observations (USFWS, unpublished data). In localized aerial surveys on the southwestern coast, between Cabo Rojo and Ponce, sightings were common throughout the region, but concentrated at Cabo Rojo, Bahía Fosforescente and Montalva in Lajas, and bahías de Guayanilla and Tallaboa in Guayanilla (Mignucci-Giannoni et al. 2006). Of manatees whose behaviors were noted in this local study, most were traveling (39%), surfacing (19%), or feeding (17%). The USFWS is currently reviewing and updating the aerial survey methods to account for detection probability, which should provide a better estimate of population abundance. Preliminary results from these efforts estimate a population size of 342 to 802 individuals with a 95% credible interval (M. Krachey, NCSU, personal communication).

Between 1992 and 2006, the USGS radio tagged and tracked the movement of 33 manatees, primarily in southwest and eastern Puerto Rico, including Vieques (Slone et al. 2006). These data describe manatee daily movements relative to freshwater and seagrass resources as well as longer movements along the coast and across open waters between the main island and Vieques. One individual traveled around the northwest coast of the island from Río Guanajibo (west) to Loiza (northeast) and back, confirming occasional long distance movements and manatee use of a portion of the north coast, where manatees had not been frequently detected through aerial surveys. High use areas by manatees tagged in the region of Roosevelt Roads Naval Station (RRNS) included the neighboring areas of Puerto Medio Mundo, Puerca Bay, and the bays southwest of RRNS, as well as waters around Vieques, especially the northwest coast and southern bays. Manatees tagged on the southwestern coast of Puerto Rico made heavy use of waters near Río Guanajibo, Puerto Real, Boquerón, Montalva, Guánica, and Guayanilla. Although Bahía de Jobos is a known high manatee use area, no tagging efforts were conducted in this region, and so there are no tracking data to provide inference about manatee movements there.

Data from carcass recovery surveys conducted from 1945-1990 identify high numbers of carcasses in regions around RRNS, Boquerón, Guayanilla, San Juan, Bahía de Jobos, and Luquillo (Mignucci-Giannoni et al. 2000), but are unable to confirm vessel strikes as the primary cause of mortality. Slone et al. (2006) noted, where the studies overlapped geographically, a positive correlation between the heavy use areas in the telemetry study and the high carcass recovery rates in the mortality study. Vieques Island was an exception to this general observation, with frequent visits by manatees but no associated mortality data.

4.1.2 Natural History

The original Recovery Plan noted that the natural history of manatees in Puerto Rico primarily draws from studies in Florida. Significant recent additions to the study of manatee natural history in Puerto Rico relate to the original Recovery Plan subsections: habitat (Lefebvre et al 2000; Reid et al. 2007), food habits (Alves-Stanley et al. 2010; Lefebvre et al. 2000), activity patterns (Slone et al. 2006; Reid et al. 2007), adverse influences (Mignucci-Giannoni et al. 2000), health (Wong et al. 2012), and genetics (Hunter et al. Submitted).

Lefebvre et al. (2000) argues that manatees in Puerto Rico probably do not exhibit seasonal long-distance travel patterns because, unlike the manatees in Florida, they do not need to seek thermal refugia during the winter months. The telemetry studies confirm that individual manatees in Puerto Rico have fidelity to relatively discrete areas, but may move longer distances through nearshore and coastal waters to other use areas (Slone et al. 2006). Compared to Florida, limited sheltered areas in Puerto Rico require manatees to spend more time in open waters (Lefebvre et al. 2000). Local movement patterns show alternating use of seagrass beds for feeding and sources of freshwater for drinking (Slone et al. 2006). The diversity of movement patterns among the 33 radio tagged individuals in the telemetry studies does not allow for typifying manatee movement patterns for all of Puerto Rico. However, data from both aerial (Mignucci-Giannoni et al. 2000) and telemetry studies (Slone et al. 2006) support the general conclusion that manatees spend little to no time residing in coastal regions with high wave energy, few seagrass beds, and little fresh water access (Powell 1981).

In Puerto Rican waters, manatees generally have access to and consume three seagrass species: *Halodule wrightii*, *Syringodium filiforme*, and *Thalassia testudinum* (Alves-Stanley et al. 2010; Lafebvre et al. 2000; Mignucci-Giannoni and Beck 1998). The widespread and abundant *T. testudinum* is the most common forage consumed by manatees in Puerto Rico (Mignucci-Giannoni and Beck 1998). Of 115 feeding observations by Lefebvre et al. (2000), 59% were in *T. testudinum* or mixed beds dominated by this species, and 38% were in *H. wrightii* monotypic stands. However, given that *T. testudinum* is by far the most abundant species, a comparison of seagrass species availability versus use led these authors to suggest an apparent preference for *H. wrightii*. An isotopic study of manatees confirmed that manatees in Puerto Rico primarily consume seagrass and found no evidence of regional variation in the diet (Alves-Stanley et al. 2010).

Although manatees do occasionally graze in open waters, most grazing activity occurs in shallow coves and bays protected from wave action (Powell 1981; Lefebvre et al. 2000; Slone et al. 2006). Within the region frequented by the tagged manatees, seagrasses grow to depths greater than 20 m. However, manatee grazing may be restricted to water depths less than 5 m; Lefebvre et al. (2000) observed grazing activity most frequently in waters ≤2.0 m (N = 115 feeding observations, mean depth = 2.03 m, depth range = 1 to 5 m).

Manatees require freshwater for drinking (Ortiz et al. 1998). Sources of freshwater can be streams/rivers, industrial plant or storm sewer output, and dump water from boats. Powell (1981) observed 85.8% of manatees within 5 km of natural or artificial freshwater sources. Manatees do not appear to discriminate between natural sources and wastewater or other industrial outflows (Powell 1981; Slone et al. 2006).

Telemetry studies (Slone et al. 2006) provide additional insight into manatee dependence on fresh water resources. Freshwater access is defined as the significance of the freshwater resource (volume of flow and reliability over time) and ability for manatees to access/utilize it (J. Reid, personal communication). While telemetry studies provide an understanding of animal movement over specific spatial scales (Hooker and Baird 2001) this method of tracking cannot estimate the use of resources except by inference. Therefore, manatee behavior concerning the use of freshwater resources is typically validated by site visits to confirm the resource as well as documenting drinking and any alternate behaviors at these sites (J, Reid, personal communication). Within areas where freshwater was in close proximity, radio tagged manatees accessed a freshwater source about every 24-36 hours. An association with freshwater appeared even greater for females nursing their calves (J. Reid, personal observation).

### 4.1.3 Anthropogenic Threats to Manatees

The nature of anthropogenic threats to manatees appears to have changed over the years. While the original Recovery Plan cites poaching, bycatch, and entanglement as the most severe threats, they are no longer identified as significant causes of take or mortality. Mignucci-Giannoni et al. (2000) collected carcass salvage data from 1990 to 1995 and compared these against historical mortality records (earliest record 1864). In the historical records, anthropogenically caused mortality resulted from capture (57.5%), watercraft collision (29.8%), being shot or speared (8.5%), and accidental entanglement (4.2%). Through effective education programs and changing cultural values, poaching no longer presents a significant threat in Puerto Rico. None of the deaths reported since 1975 were attributed to poaching for meat (Mignucci-Giannoni et al. 2000). More recently, watercraft collisions appear the greatest direct anthropogenic threat to manatees in Puerto Rican waters. Collisions occur from both boats and personal watercraft (e.g., jet skis). Between 1990 and 1995, mortality events attributed to watercraft collisions increased to 50.0% while capture decreased to 31.3%.

Studies in Florida note a strong correlation between an increase in the number of registered boats and reported manatee mortality (Ackerman et al. 1995), but similar studies have not been conducted in the more open habitats of Puerto Rico. Evidence suggests that high-speed impacts and associated blunt trauma, rather than propeller injuries, are the underlying factors in watercraft collision mortality events in Puerto Rico (Mignucci-Giannoni et al. 2000; Lightsey et al. 2006). Calves that have not yet learned to avoid boats may be at greater risk than adults (Mignucci-Giannoni et al. 2000). Regions with the highest incidence of carcass recovery between the years of 1990 through 1995 were reported as: Fajardo, Ceiba, Bahía de Jobos, Toa Baja, Guayanilla, Cabo Rojo, and Río Grande to Luquillo (Mignucci-Giannoni et al. 2000). Enforcing reduced speed zones in areas with high manatee concentrations has been shown to reduce mortality in Florida (Laist and Shaw 2006), but similar research has not been conducted in Puerto Rico.

## 4.2 Workshops and Surveys

The first workshop, held in September 2010 at the Cabo Rojo National Wildlife Refuge, was attended by 20 experts. The second workshop, held in November 2010 at the Bahía de Jobos National Estuarine Research Reserve, was attended by nine experts, including one person not present at the first meeting. Participants included representatives from the following agencies: USFWS (7), PRDNER (4), Interamerican University of Puerto Rico (3), U.S. Geological Survey (2), Bahía de Jobos National Estuarine Research Reserve (2), University of Puerto Rico (1), and PBS&J International, Inc. (1). In reporting elicitation results, we do not again cite the primary literature (see previous section). Instead, we present expert reasoning and consensus decisions regarding how best to implement these published data and their collective experiences in a regional assessment of potential MPA locations. Collectively, the experts' knowledge included familiarity of the original Recovery Plan, most studies cited in that plan, and most research highlighted in our literature review. The comments and results presented here therefore represent experts' synthesis of all information resources.

### 4.2.1 Target, Scope, and Vision

Manatees in Puerto Rico were pre-defined as the conservation target for this project. Through group consensus, experts articulated a vision statement and the project scope (Table 2). The vision statement from the first workshop defined general manatee conservation objectives, while the second workshop provided vision and scope statements specific to an MPA. The scope statement defined the geographic range for the data search, as well as the range over which the final model and revised Recovery Plan would apply (Figure 2). The islands of Mona, Monito, and Desecheo were excluded from the scope due to the lack of empirical evidence or knowledge of manatees traveling to

Table 2. The scope and vision statements of participating experts as elicited in the first (entire population) and second (population within MPAs) workshops.

| | Entire Population | Population Within MPAs |
|---|---|---|
| **Scope** | • the coastal shelf and estuarine waters of Puerto Rico excluding Mona, Monito, Desecheo Islands, and the US Virgin Islands | • an area providing access to seagrass, sheltered waters, and freshwater within a 5 km radius where an MPA would reduce take |
| **Vision** | • the long term conservation and recovery of the endangered Antillean Manatee and its habitats in coastal-shelf and estuarine waters in Puerto Rico | • the prevention of anthropogenic take, harassment, and disturbance of manatees within an area that provides high quality habitat |

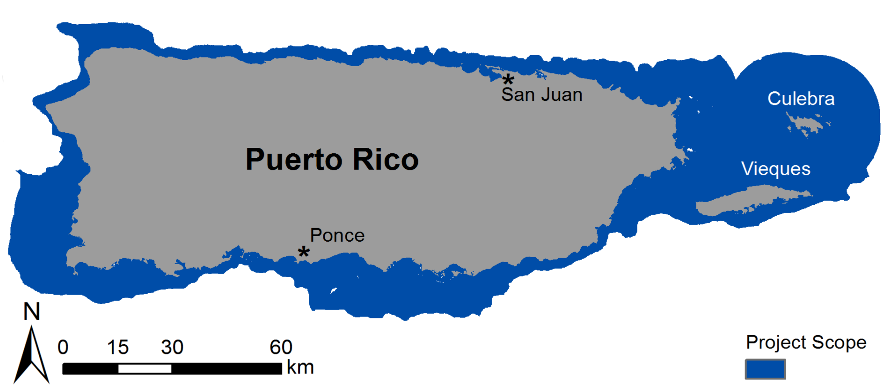


Figure 2. The project scope (blue) as defined by expert consensus included all estuarine and coastal waters extending to the nearer of 9 nm (territorial waters limit) or the 200 m depth contour, but excluding the islands of Mona, Monito, and Desecheo and their associated coastal waters.

those locations. The scope of an MPA defined the geographic and thematic elements by which we would identify and evaluate potential MPA regions.

### 4.2.2 Target Status Assessment

The new manatee population survey methods in development for the USFWS will provide more accurate and precise estimates of population size. However, even as estimates of population size become more robust, there remain many questions about other aspects of manatee population health and vital rates (e.g., potential changes in disease and contaminant prevalence, sex ratios, age-specific birth and death rates, genetic diversity, etc.). Experts agreed that manatee take (e.g., anthropogenic sources of mortality or stress) is an important factor of the overall threat to manatees. Knowledge of manatee mortality from stranding data highlight the significance of watercraft collision events (Mignucci-Giannoni et al. 2000), but experts acknowledged the challenging need to gather more comprehensive and standardized mortality data to address potential reporting and collection biases. Furthermore, many mortality events cannot be attributed to a specific cause (e.g. due to poor carcass condition). Experts agreed it was plausible that cumulative effects of various environmental health risks (USGS 2010; Bonde et al. 2004) could together represent a risk as great as watercraft. They agreed that such threats would not be mitigated through management actions within an MPA boundary, but noted that if present and unaccounted for, such threats could confound efforts to achieve and measure success of an MPA.

The lack of information pertaining to the population estimate and biological history prevented experts from agreeing to a single measure of target status for manatees in Puerto Rico (see further discussion in the revised Recovery Plan). Experts did propose several metrics to assess population status that could be incorporated into the revised Recovery Plan baseline studies and ongoing monitoring efforts. However, experts concurred that any change in population status, positive or negative, would be difficult to attribute directly to MPA effectiveness, as individual manatees would regularly travel to and from the MPA. Thus it is suggested that measures of success for an MPA should *not* be the same as measures of success for manatee population recovery.

Difficulties in developing predictive models should not diminish the importance of implementing MPAs as a strategy, but instead emphasize the need to establish explicit conservation objectives along with monitoring programs to measure their effectiveness and adaptively improve implementation of this strategy. Until direct measures of MPA success can be defined (e.g., MPA impacts on manatee populations), experts agreed that indirect measures could provide valuable insight into MPA effectiveness. Therefore, monitoring programs should take into account both human and ecological responses to MPAs. For example, if an MPA is designed to reduce take by regulating boat activity, boater surveys could provide information on whether boating regulations are impacting boating behavior within the MPA boundary. If MPA regulations fail to change boating behavior, then these regulations will be ineffective at reducing manatee take. Data collected by monitoring MPAs and from other recovery activities will help to identify demographic parameters and provide a better understanding of manatee behavior and relationships to habitat. As this information becomes available, predictive models can be developed further to assess the effectiveness of MPAs. Finally, to accurately monitor the effects of MPAs it will be necessary to quantify the state of a system both before and after a management intervention (Field et al. 2007). As current

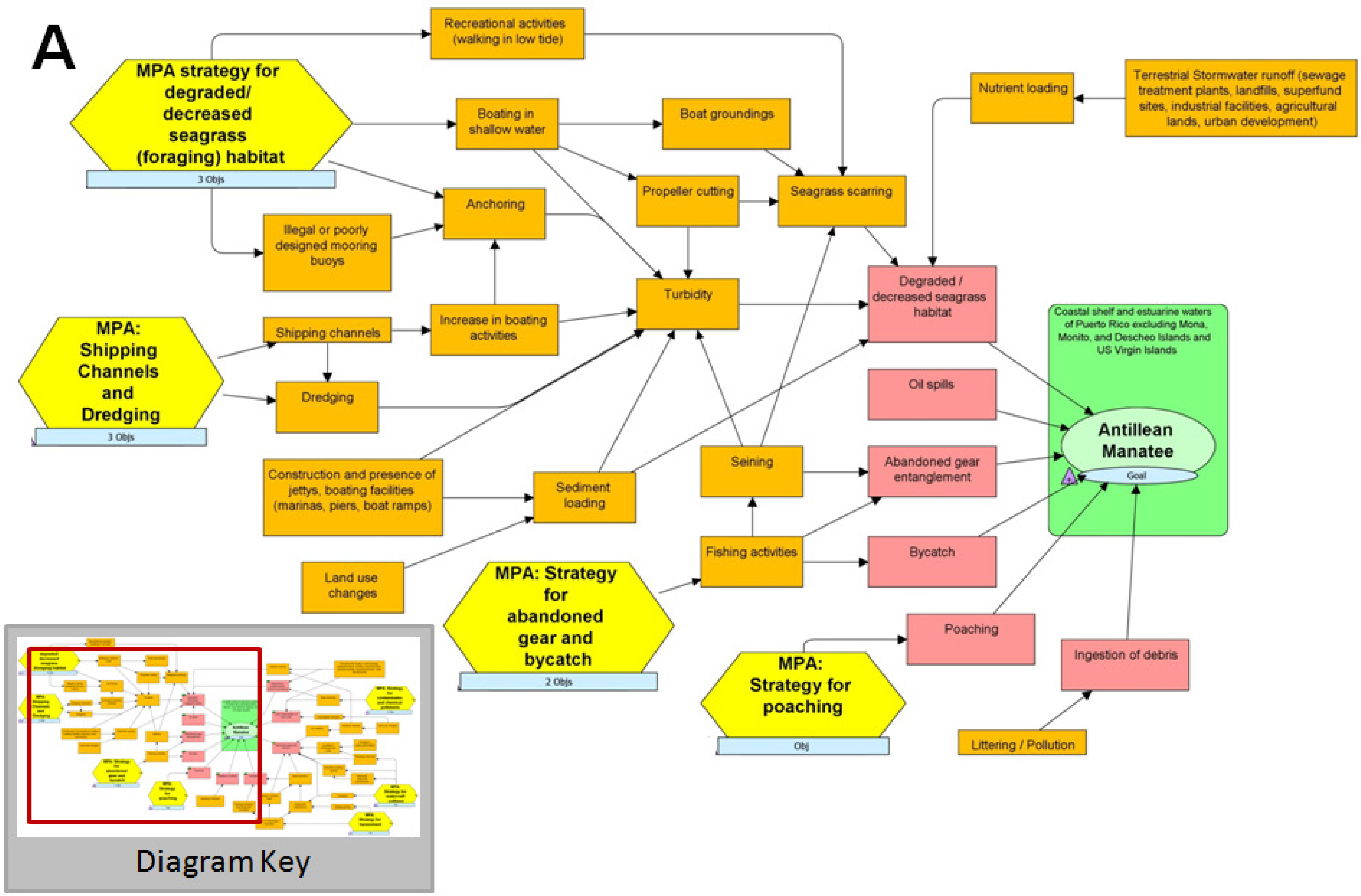


Figure 3A. Left side of conceptual diagram (full diagram shown in diagram key) depicting target (green oval), direct threats (pink rectangles), indirect threats (orange rectangles), and MPA strategies (yellow hexagons).

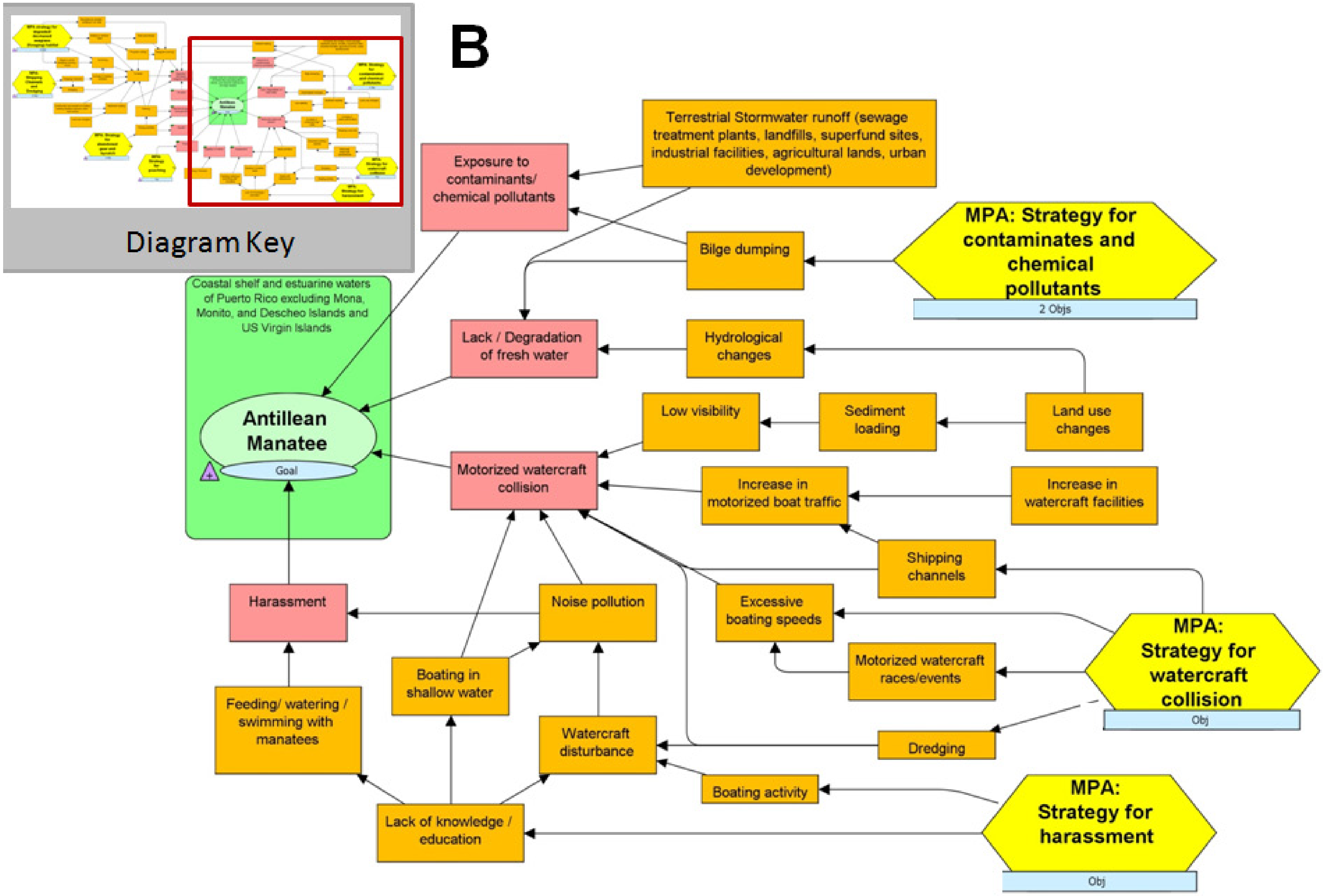


Figure 3B. Right side of conceptual diagram (full diagram shown in diagram key) depicting target (green oval), direct threats (pink rectangles), indirect threats (orange rectangles), and MPA strategies (yellow hexagons).

spatial data are inadequate without validation of the presence of key ecological resources, we suggest MPA design is incomplete without site visits and surveys to assess baseline conditions.

4.2.3 Conceptual Diagram

Two products of the workshops and surveys were a list of key ecological attributes (Table 3) and a conceptual diagram (Figure 3) defining the relationships between the target, threats, and management strategies. This diagram captures all potential threats as they relate to manatees and is not limited to those able to be mitigated through MPA establishment (i.e., terrestrial land use impacting water quality). This diagram is described and discussed in detail within the revised Recovery Plan. In this report, we focus only on the components relevant to MPA implementation.

Table 3. Key ecological attributes of manatee for inclusion in MPA regional evaluation with the metrics that should be considered when defining attribute value and summary of spatial data resources.

| Key Ecological Attribute | Description of Metrics Defining Value of Attribute | Spatial Data Resources (Source Agency) |
|---|---|---|
| Seagrass | • Presence within feeding depths<br>• Abundance<br>• Species composition | Benthic habitat maps provide percent cover, but not species composition (NOAA) |
| Freshwater | • Presence<br>• Abundance | Coastal outflows from perennial streams, wastewater treatment plants, and hydroelectric plants (USGS, EPA, AAA) |
| Shelter | • Presence | Wave energy model of shallow waters with low wave energy (USGS) |

4.2.4 Key Ecological Attributes

Following extensive discussion and revision of spatial analysis methods (Appendix 2), experts described three primary key ecological attributes necessary to manatee long-term survival: seagrass, freshwater, and shelter (Table 3). While experts unanimously agreed these attributes must be present, they debated the roles of resource quantity and quality. Further discussion of manatee behavior led experts to identify water depth as a characteristic that modifies the value of the key ecological attributes. Although manatees regularly traverse deep water when moving between local sites or resources, experts hypothesized that manatees do not feed or rest in waters greater than 13 m depth (Figure 4) and spend the majority of their time in waters less than 5 m deep. Therefore, experts indicated that any assessment of seagrass as a manatee foraging habitat should be restricted to these shallower waters (< 13 m). A final result of the key ecological attribute discussions was the spatial relationship among the attributes. While manatees have been observed to move long distance and there is great variance among individuals regarding daily movement distances, there was consensus that these attributes should exist in proximity within an MPA. Experts were not able to provide insight into potential water depths or characteristics for travel corridors, nor was there any information available within the literature. A 5 km radius was identified as a scale that captured the local movements of most manatees in the telemetry studies. This scale also fit with water resource use observations of Powell (1981). Thus, in all MPA data analyses, the presence or abundance of a resource was always referenced against this scale.

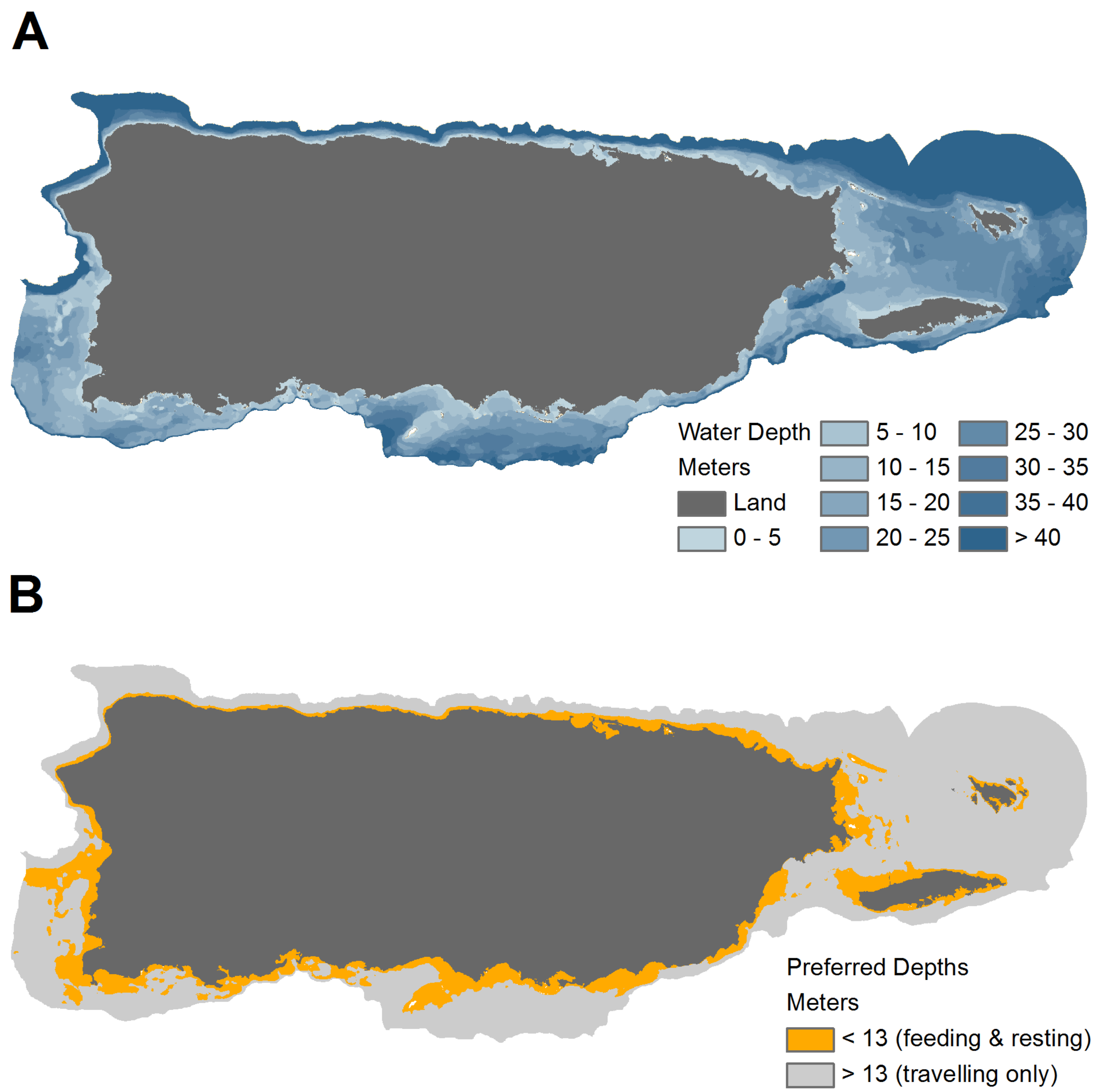


Figure 4. (A) Bathymetry within the MPA project scope. (B) Manatee foraging and resting was hypothesized to be restricted to shallow waters (<13 m depth) with deeper waters used for traveling between resources located in shallow waters.

*4.2.4.1 Seagrass*

Experts described four species of seagrass as common within the project scope: *T. testudinum*, *S. filiforme*, *Halodule wrightii*, and *Halophila decipiens*. However, only the first three were identified as forage for manatee (Mignucci-Giannoni and Beck 1998), as *H. decipiens* predominantly occurs in deeper water (10 to 30 m depth). They noted that manatees may prefer *H. wrightii* above *T. testudinum*, but that *T. testudinum* was the most abundant and therefore likely the most frequently consumed species. If manatees do prefer certain seagrass species, there is no evidence to indicate whether these preferences correlate with individual or population level benefits. Several experts hypothesized that manatees actively seek a diversity of seagrass species for their diet, as different seagrass species likely offer different nutritional value.

To spatially model the extent and value of seagrass to manatees, we extracted the seagrass cover data from NOAA's benthic habitat maps (Kendall et al. 2001). These data delineate areas (polygons) of seagrass habitat attributed as continuous or patchy, and if patchy, attributed with a percent cover classification (10-30%, 30-50%, 50-70%, or 70-90%). Experts chose to ignore the patchiness data, hypothesizing that manatees do not actively select foraging sites based on

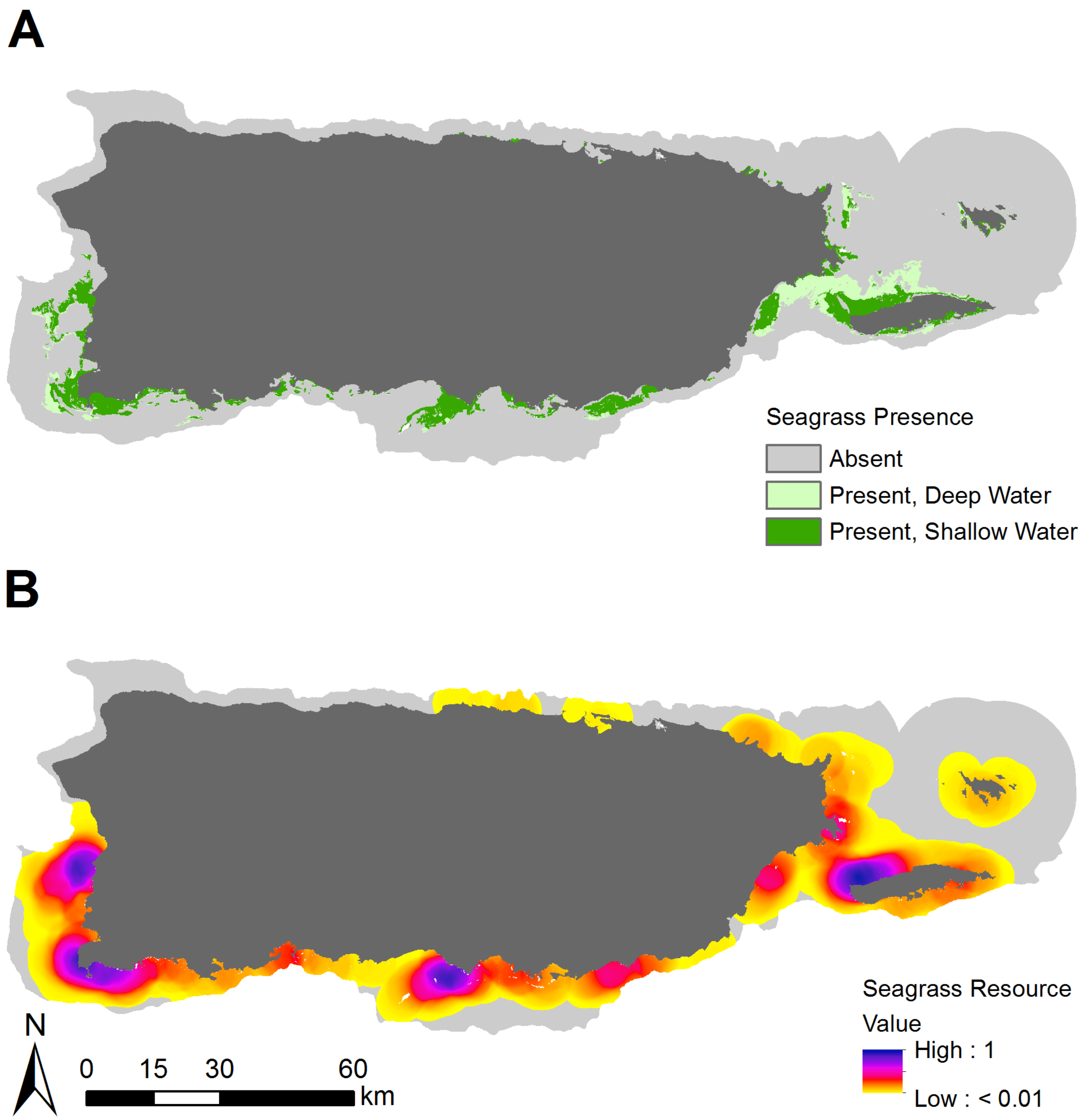


Figure 5. (A) Seagrass presence in deep (>13 m) and shallow (<13 m) water within the project scope. Only seagrass within shallow water was considered available to foraging manatees. Seagrass grid cells were assigned a decreasing linear value (1 to 0) from 1 m to 13 m depth (not shown). (B) The relative value of sites based on the summed value of seagrass habitat within a 5 km radius, scaled relative to the maximum. Light gray areas have zero seagrass resource value.

patchiness, but rather on the presence of seagrass within suitable water depths (<13 m depth, Figure 5A). Furthermore, due to the coarseness of the data resolution, we excluded consideration of any individual foraging effects on the seagrass cover. Furthermore, but with less certainty, they agreed that the hypothesized value of seagrass habitat as a foraging resource could be reasonably represented with a linear decreasing function of depth from 1 m to the 13 m use limit. Thus, after converting the vector polygon data to 30 m raster grid format, we attributed each seagrass grid cell with a resource value based on its depth (from 1 m = 1 to 14 m or greater = 0). Then, for each grid cell within the scope, we summed all values within a 5 k radius and, finally, rescaled the results relative to the maximum calculated value within the scope (Figure 5B).

Results of this analysis revealed several areas of concentrated, high scoring grid cells or "hotspots." For the purposes of this report, hotspots are referenced based on their proximity to municipal coastlines as requested by the FWS and contributors (Figure 6). The municipalities with coastlines bordering seagrass hotspots were, in alphabetical order: Arroyo, Cabo Rojo, Ceiba, Guayama, Guayanilla, Humacao, Lajas, Mayagüez, Naguabo, Patillas, Peñuelas, Salinas, Santa Isabel, and Vieques.

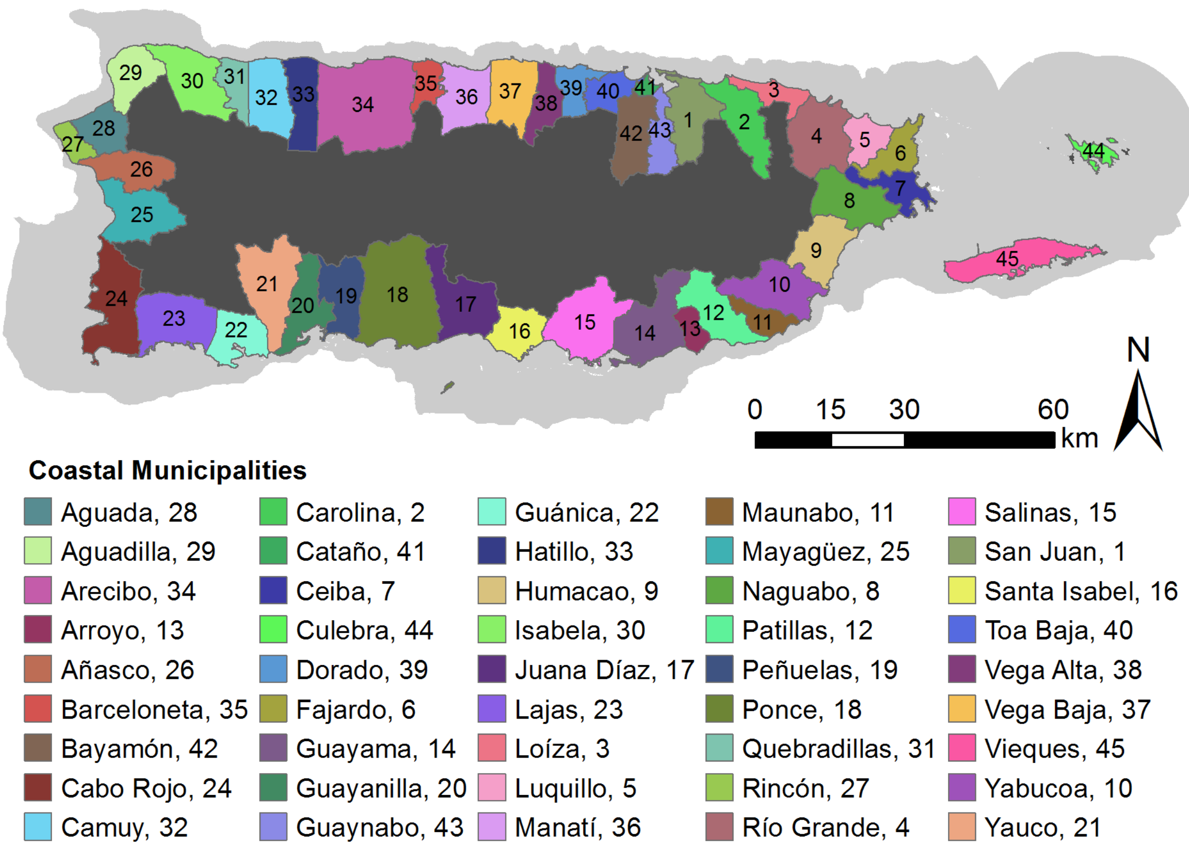


Figure 6. Coastal municipalities of Puerto Rico, listed in alphabetical order. Numbers begin in San Juan and continue clockwise around the island.

*4.2.4.2 Freshwater*

All experts agreed that (1) manatees require regular access to freshwater, (2) 5 km represents a reasonable distance to characterize manatee daily local movement relative to a preferred freshwater resource, (3) manatees appeared not to exhibit a preference for natural over anthropogenic freshwater resources, and (4) the impact of poor water quality was unknown, although manatees did not appear to avoid impaired waters or waters that do not meet water quality standards set by the Clean Water Act, even after pollution controls are applied (Environmental Protection Agency 2010). Manatees can obtain freshwater from the mouths of streams and rivers, coastal groundwater springs, industrial wastewater (e.g., wastewater treatment plants, hydroelectric power plants) and

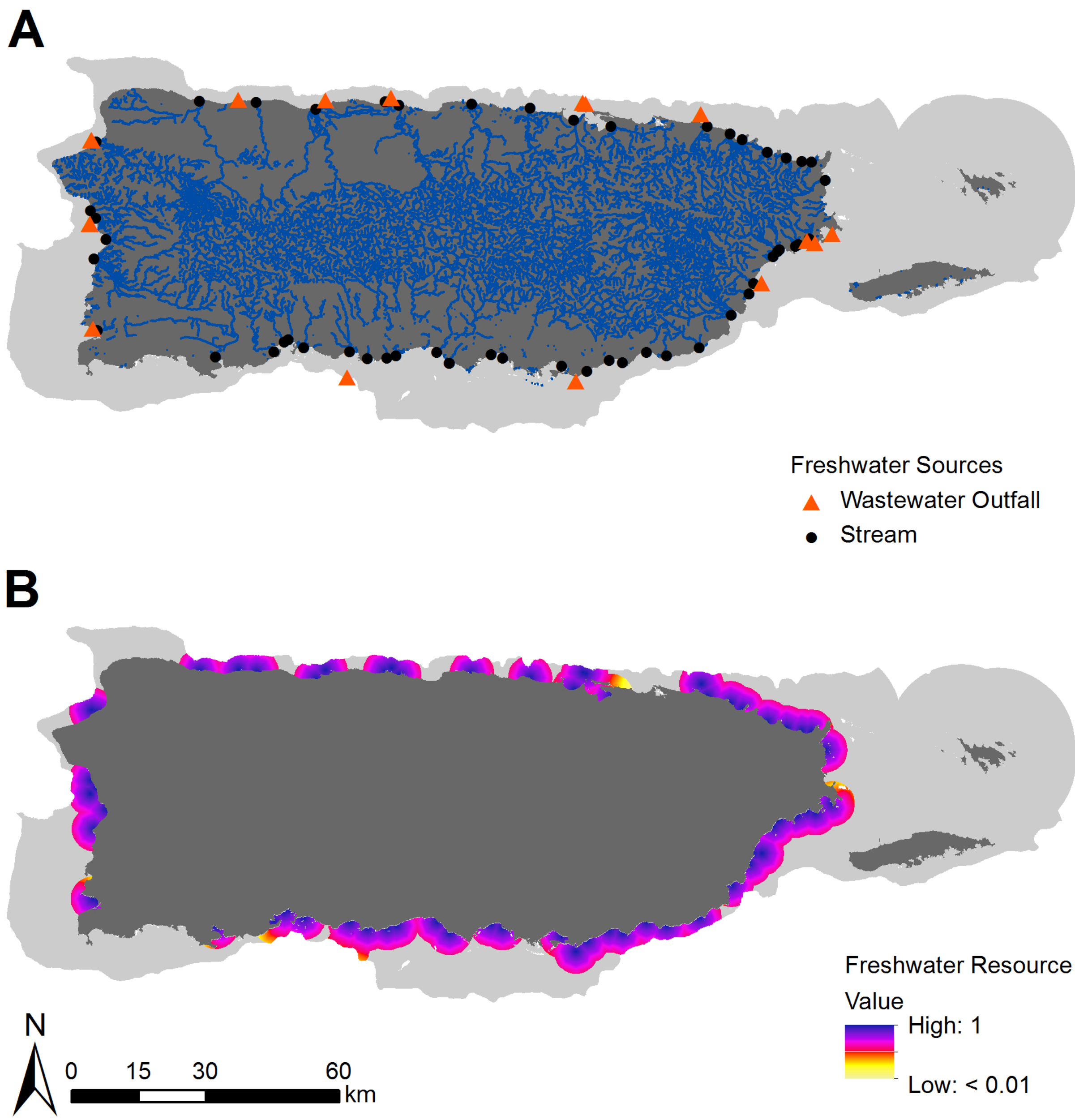


Figure 7. (A) Freshwater resources within the MPA project scope for which outflow coordinate data were available. (B) The resource value is the total number of freshwater sources within a 5 km radius, summed and then rescaled relative to the maximum value of 16. Light gray areas have zero freshwater resource value.

storm sewer outflows, natural intermittent drainages through coastal forests, and watering stations set out on boats or docks by locals and tourists. Watering stations, however, were identified as a threat rather than a resource. In total, 73 mapped freshwater resource point locations were identified (Figure 7A). These sites were predominantly major streams (54 outflow points) as identified in the Atlas Ambiental de Puerto Rico (Chapter 9: López Marrero & Villanueva Colón 2006). Waste water treatment outflow data (19 points) were obtained from the Autoridad de Acueductos y Alcantarillados (M. Olaya, AAA, personal communication) and from a Naval Activity Puerto Rico report (Geomarine 2004). These data were confirmed via the Environmental Protection Agency Permit Compliance System (USEPA 2005).

To calculate regional resource value, we first converted the vector point data to 30 m raster grid cell data. Each raster grid cell with a freshwater source was valued at one and all others within the scope were valued at zero. Then, for each grid cell, we calculated the distance to the nearest freshwater point resource. We calculated distance as the shortest path avoiding land. The final step was to rescale these data from zero to one by dividing all grid cell values by the maximum calculated distance value (Figure 7B).

Most municipalities were associated with one or more freshwater resources. The only municipalities *lacking* mapped freshwater resources were, in alphabetical order: Carolina, Culebra, Lajas, Rincón, Vieques, and Yauco. Freshwater resources were most limiting in the northwest and southwest regions of the island as well as at the islands in the east.

### *4.2.4.3 Shelter*

Although manatees in Puerto Rico spend much more time traversing open coastal waters than manatee populations in Florida or other regions, experts agreed that they require sheltered waters for feeding and resting. Sheltered waters are shallow bays and coves (< 3 m depth) with low wave energy (< 0.3 m wave height). We generated a shelter model from available bathymetric

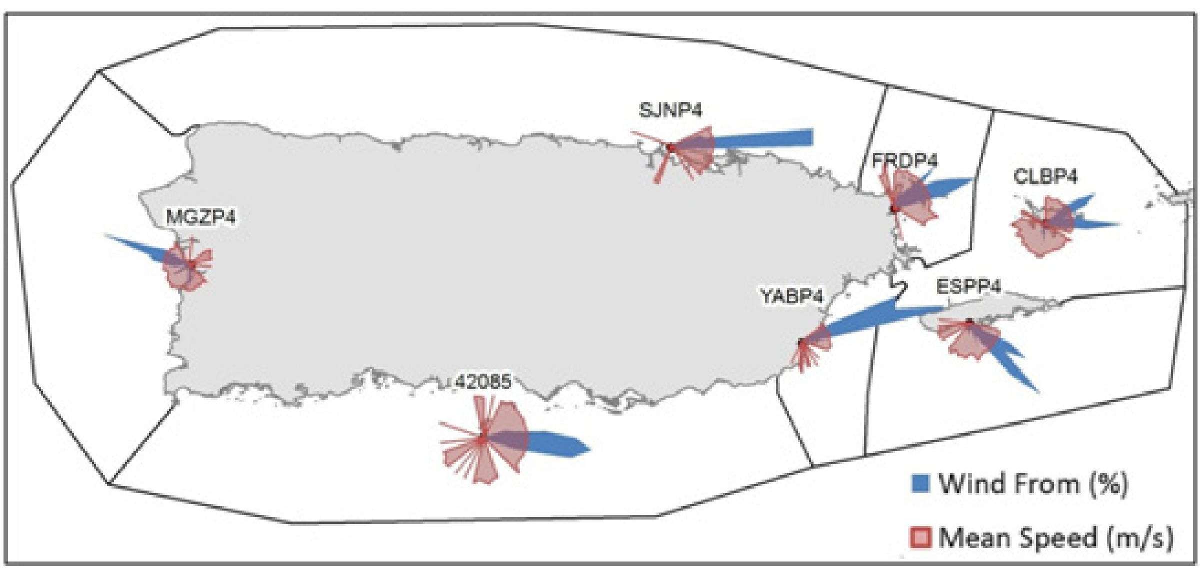


Figure 8. Stations used to define wind speed and direction within project scope. Locations are Mayaguez (MGZP4), San Juan (SJNP4), Fajardo (FRDP4), Culebra (CLBP4), Esperanza (ESPP4), Yabucoa (YABP4), and offshore south of Ponce (42085).

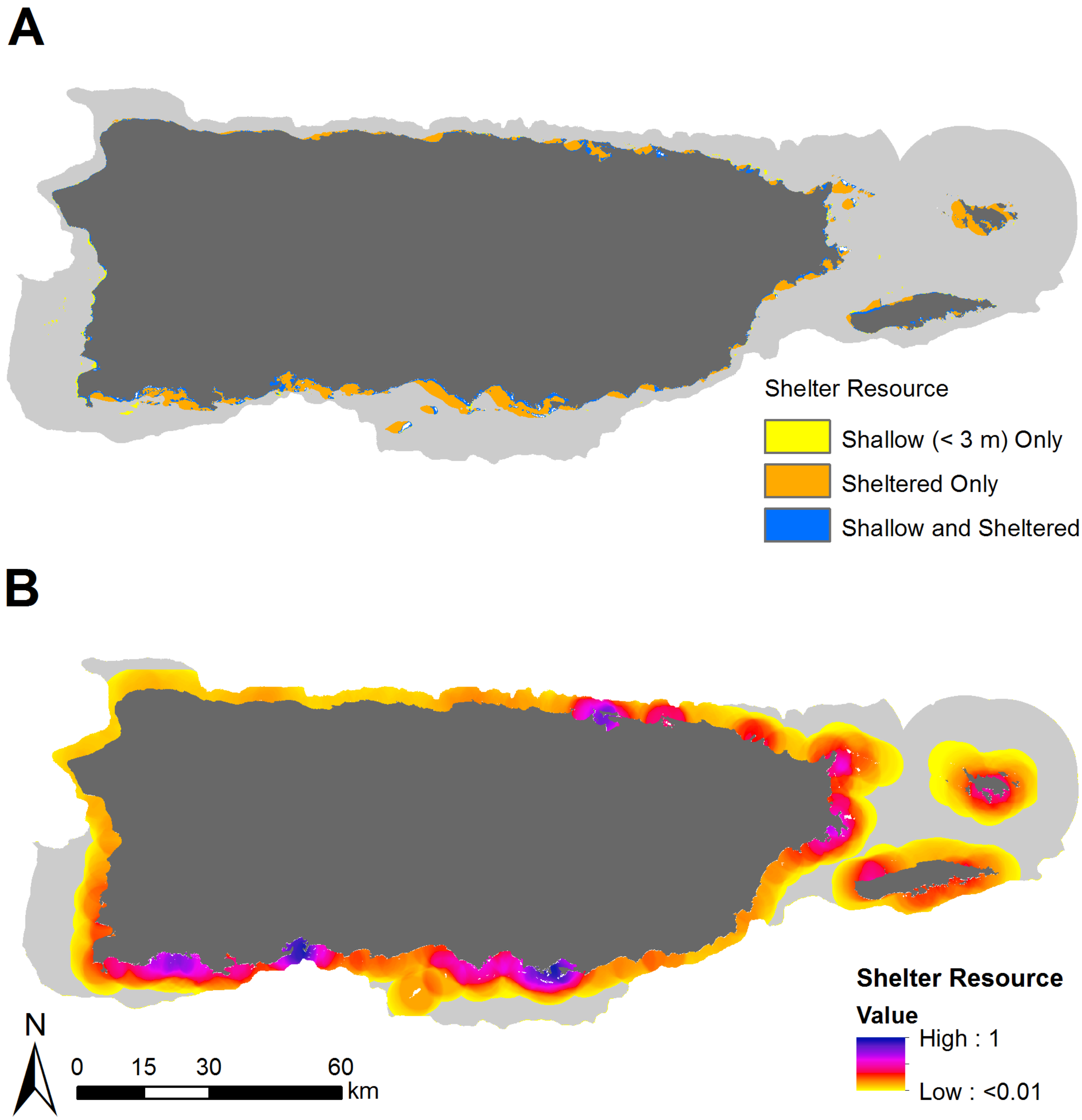


Figure 9. (A) Regions offering shallow, sheltered, or both shallow and sheltered waters to manatees based an wave energy model and manatee movement patterns. (B) Relative shelter value of coastal waters for manatees based on total area of shelter within 5 km radius (maximum = 1044 ha). Light gray areas have zero shelter value.

(Figure 4A) and wind data (Figure 8) using the NOAA modeling package Wave Exposure Model (WEMO 4.0; http://www.ccfhr.noaa.gov/stressors/wemo/). This package uses coastal bathymetry, landforms and wind data to predict the magnitude of wave energy that exists in a given location. The model output distinguished between sheltered waters that were also shallow, waters that were sheltered but not shallow, and waters that were shallow but not sheltered (Figure 9A). As the higher value of shallow waters had already been included in the seagrass model, and the value of sheltered waters for both foraging and resting extended beyond the 3.0 m shallow depth limit of the shelter model, we chose to combine both sheltered classes into a single class. To calculate the resource value of each 30 m raster grid cell within the scope, we summed the total area of sheltered waters within a 5 km radius and then rescaled the results to a zero to one scale by dividing by the maximum calculated area (Figure 9B).

Municipal coastlines with high shelter resource value occurred, in alphabetical order: Cabo Rojo, Carolina, Cataño, Ceiba, Culebra, Fajardo, Guánica, Guayama, Guayanilla, Guaynabo, Juana Díaz, Lajas, Loíza, Peñuelas, Salinas, San Juan, Santa Isabel, Toa Baja, and Vieques.

### 4.2.5 Threats

The Miradi conceptual diagram included ten direct threats to manatees (Table 4). Table 5 presents the impacts of these direct (and indirect) threats on manatees and seagrass. When experts' rank scores for individual threats were analyzed within Miradi, watercraft collisions were the greatest single threat to manatees (Table 4). However, cumulatively, the other threats could have a medium impact. Stranding data and mortality studies support the conclusion that watercraft collisions are a major and growing threat. However, some experts questioned whether watercraft threat was truly the greatest threat or merely the best studied and documented threat. These experts pointed to the 2000-2010 manatee mortality data (PRDENR, unpublished data) where only eight of seventy-seven records (10%) were attributed to watercraft, while ten (13%) were attributed to illness, and fifteen (19%) were dependent calves. The majority of mortality events (thirty-nine records, 51%) were due to unidentified causes. Whether the illness or unknown cases could reflect health threats of anthropogenic origin is unknown as such threats are poorly studied or not well captured by current mortality survey methods. Importantly, however, experts identified motorized watercraft as the primary threat that could be addressed via establishment and enforcement of an MPA. Furthermore, motorized watercraft collision was the only threat readily modeled across the entire scope given available spatial data.

Table 4. Watercraft collision ranked highest among direct threats. Direct threat rank scores (Low, Medium, or High) were calculated in Miradi based on scores for three threat attributes: Scope, Severity, and Irreversibility.

| Threat | Scope | Severity | Irreversibility | Threat Ranking |
|---|---|---|---|---|
| Abandoned gear entanglement | Med | Med | High | Med |
| Bycatch | Low | Low | Low | Low |
| Degraded/ decreased seagrass habitat | Low | Low | Med | Low |
| Exposure to contaminants/ chemical pollutants | Low | Med | High | Low |
| Harassment | Very High | Med | Med | Med |
| Ingestion of debris | Low | Low | High | Low |
| Lack/ degradation of fresh water | Low | High | High | Low |
| **Watercraft collision** | **High** | **High** | **Med** | **High** |
| Oil Spills | Low | High | High | Low |
| Poaching | Low | Low | Low | Low |

Table 5. Impacts of indirect and direct threats on targets and their key ecological attributes. Impacts: Degradation of seagrass habitats (H), Manatee injury or death (M), Purposeful take (T), Accidental take (A), Disruption of trophic system (D), Bycatch (B), Restrict access to key ecological attribute (R)

| | | | | | Target | Key Ecological Attribute | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Seagrass | | | |
| | Indirect Threat | Indirect Threat | Direct Threat | Impact | Manatee | Diversity | Extent | Fresh water | Shelter |
| 1 | | Anchoring | Turbidity / Seagrass scarring | H | | x | x | | |
| 2 | | Dredging | Turbidity / Seagrass scarring | H | | x | x | | x |
| 3 | | Construction and presence of piers, marinas, and boat ramps | Turbidity / Seagrass scarring | H | | x | x | | |
| 4 | Boating in shallow water | Propeller Cutting | Turbidity / Seagrass scarring | H | | x | x | | |
| 5 | Boating in shallow water | Boat groundings | Turbidity / Seagrass scarring | H | | x | x | | |
| 6 | | Motorized water sport race, events | Motorized watercraft collision | M, A | x | | | | |
| 7 | | Shipping channels | Motorized watercraft collision | M, A | x | | | | x |
| 8 | Construction and presence of piers, marinas, and boat ramps | Increase of motorized watercraft traffic | Motorized watercraft collision | M, A | x | | | | x |
| 9 | | Noise pollution | Motorized watercraft collision | M, A | x | | | | |
| 10 | | Boating in shallow water | Motorized watercraft collision | M, A | x | | | | |
| 11 | | Lack of awareness for manatee areas | Motorized watercraft collision | M, A | x | | | | |
| 12 | | Low visibility caused by sedimentation | Motorized watercraft collision | M, A | x | | | | |
| 13 | Any watercraft disturbance | Noise intoxication / Manatees desensitized to disturbance | Motorized watercraft collision | M, A | x | | | | |
| 14 | | Industrial Pollution | Nutrient loading /Chemical pollutants / Exposure to contaminates | H, D, M, A | x | x | x | x | |
| 15 | | Runoff (agriculture, sewage treatment plants, landfills, superfund sites | Nutrient loading /Chemical pollutants / Exposure to contaminates | H, D, M, A | x | x | x | x | |
| 16 | | | Oil spills | H, D, M, A | x | x | x | x | |

Table 5 (Continued). Impacts of indirect and direct threats on targets and their key ecological attributes. Impacts: Degradation of seagrass habitats (H), Manatee injury or death (M), Purposeful take (T), Accidental take (A), Disruption of trophic system (D), Bycatch (B), Restrict access to key ecological attribute (R)

| | | | | | Target | Key Ecological Attribute | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Seagrass | | | |
| | Indirect Threat | Indirect Threat | Direct Threat | Impact | Manatee | Diversity | Extent | Fresh water | Shelter |
| 17 | | Bilge dumping | Exposure to contaminates | M, A | x | x | | | |
| 18 | | | Net/ Abandoned gear entanglement | M, B, A | x | | | | |
| 19 | | Seining | Net/ Abandoned gear entanglement | M, B, A | x | | | | |
| 20 | | | By-catch | M, B, A | x | | | | |
| 21 | | | Poaching | M, T | x | | | | |
| 22 | | | Ingestion of debris/trash | M, A | x | | | | |
| 23 | | Swimming, watering, feeding by tourists and residents | Harassment/ Molestation | M, T | x | | | | |
| 24 | Land use changes | Hydrological changes | Decrease of Freshwater | R | | | | x | x |

### *4.2.5.1 Watercraft*

In the absence of data to directly map the coordinates of manatee-watercraft collisions, experts agreed that the distribution of boating infrastructure and activity provided the best available proxy data resource. We obtained the majority of these data from NOAA's Environmental Sensitivity Index (ESI) (NOAA 2005). Within the ESI data, we selected the socioeconomic activities relevant to the threat of watercraft collision: boat ramps, marinas, commercial fishing, Coast Guard sites, recreational fishing, and subsistence fishing (Figure 10A). We deleted any records that occurred greater than 1 km inland as outside the project scope. To update the ESI marina data, collected in 1998-1999 from aerial photography and from expert knowledge, we reviewed online marina data from Travel and Sports Puerto Rico (http://travelandsports.com/ma.htm, accessed December 2010). We identified five marinas not included in the ESI data, confirmed their presence via Google Earth, and added these points. The PRDENR provided updated location data for boat ramp facilities along the Puerto Rican coast (excluding Culebra and Vieques). These data came from a 2005 inventory of all existing and potential boat ramp sites (Dickson et al. 2005). We combined these data with the ESI data for boat ramps after mapping and visually confirming that there was no spatial overlap between the data. These data were subsequently updated with the addition of 22 boat ramp points contributed from the same ongoing study (N. Jiménez, PRDENR, unpublished data).

The PRDENR also provided boat concentration data from a report on boating impacts to reef and seagrass habitats (PRDENR 2010). Initially, these data were excluded from the boating threats model for two reasons. First, the study only researched boating concentration and impacts in select areas, so the results do not fully represent the project scope. Second, the PRDENR data do not distinguish between motorized and non-motorized watercraft, of which only the former were identified as a threat to manatees. However, experts indicated that the draft watercraft threat model underestimated watercraft activity in several regions, especially in the vicinity of southeast Puerto Rico, Vieques, and Culebra. Therefore, the PRDENR data were incorporated into the model (Figure 10A), but only as presence-only point data. We excluded the information about boating concentration (heavy versus light use) to better conform to the ESI data reporting methods. Ultimately, the inclusion of the PRDENR data did not alter which municipalities ranked highest with regards to the threat from motorized watercraft.

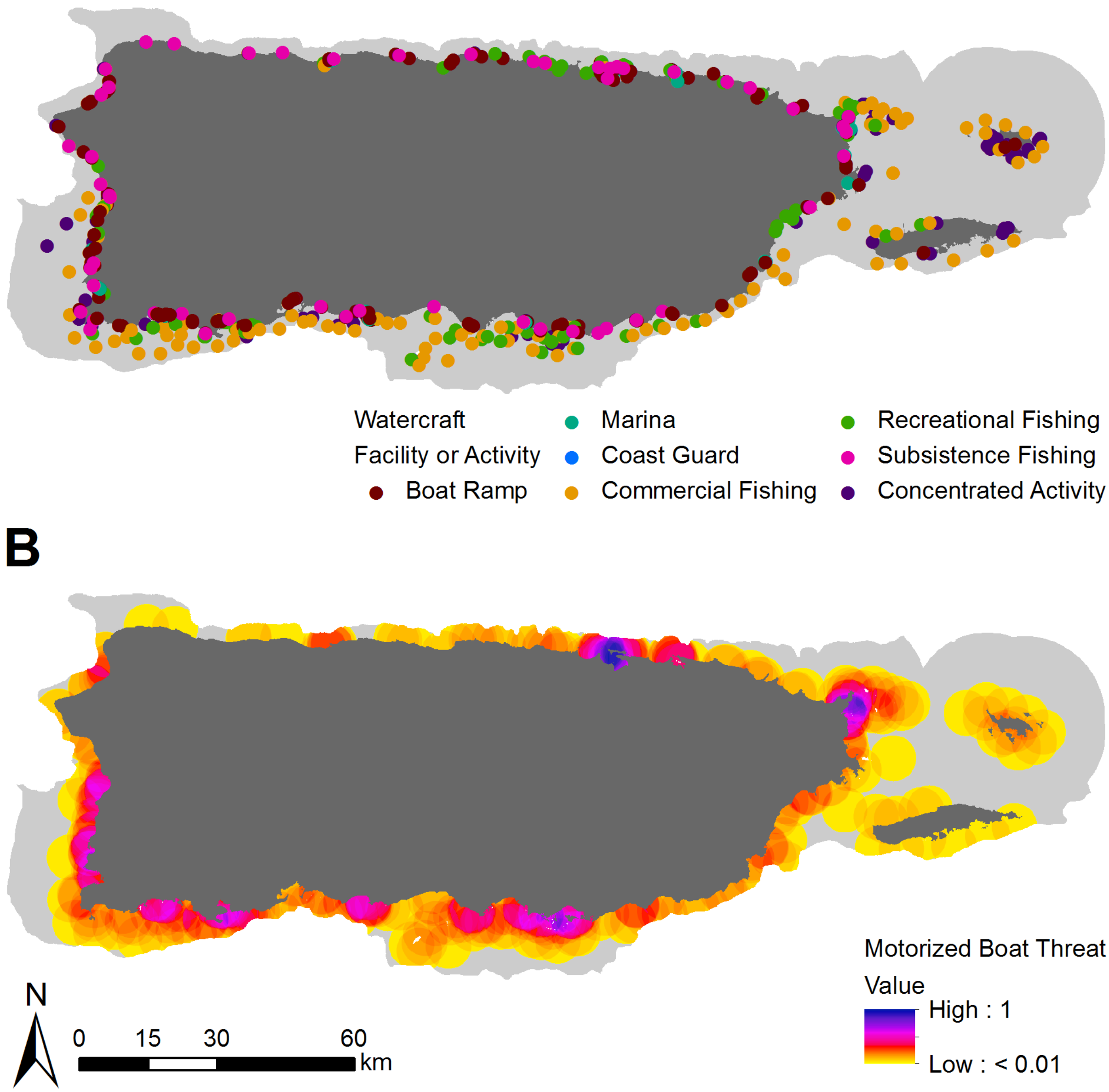


Figure 10. (A) Motorized watercraft infrastructure and activity within the MPA project scope. (B) The threat risk is the total number of watercraft facility or activity records within a 5 km radius, summed and then rescaled relative to the maximum value of 36. Light gray areas have zero motorized watercraft threat.

The final collection of mapped watercraft data included 480 points. These vector point data were converted to 30 m raster grid cells and given a value of one (all infrastructure and activity types were valued equally); all other grid cells within the scope were valued at zero. For each grid cell, we then calculated the sum of infrastructure and activity features within a 5 km radius, a scale that captures local movements of manatees. The resulting data were rescaled from zero to one by dividing by the maximum calculated abundance value (Figure 10B).

Municipalities with high motorized watercraft threat ranking were, in alphabetical order: Aguada, Aguadilla, Cabo Rojo, Carolina, Cataño, Fajardo, Guánica, Guayama, Guaynabo, Lajas, Loíza, Mayagüez, Ponce, Salinas, San Juan, Santa Isabel, Toa Baja, and Yauco.

### 4.3 Identification of Potential MPA Regions

For a given grid cell to be evaluated as a potential MPA grid cell (MPA value > 0), all key ecological attribute and threat variables for that grid cell had to have a value greater than zero (i.e., all key ecological attributes and threats must be present within 5 km). Eighty-one percent of the scope grid cells failed to meet these criteria. Within the remaining 19% (985 km2) of the project scope, MPA values ranged from 0.002 to 0.644 (Figures 11 and 12). Municipalities with the highest MPA value were, in alphabetical order: Cabo Rojo, Ceiba, Fajardo, Guánica, Guayama, Guayanilla, Mayagüez, Peñuelas, Salinas, and Santa Isabel (Figure 13A & 13B).

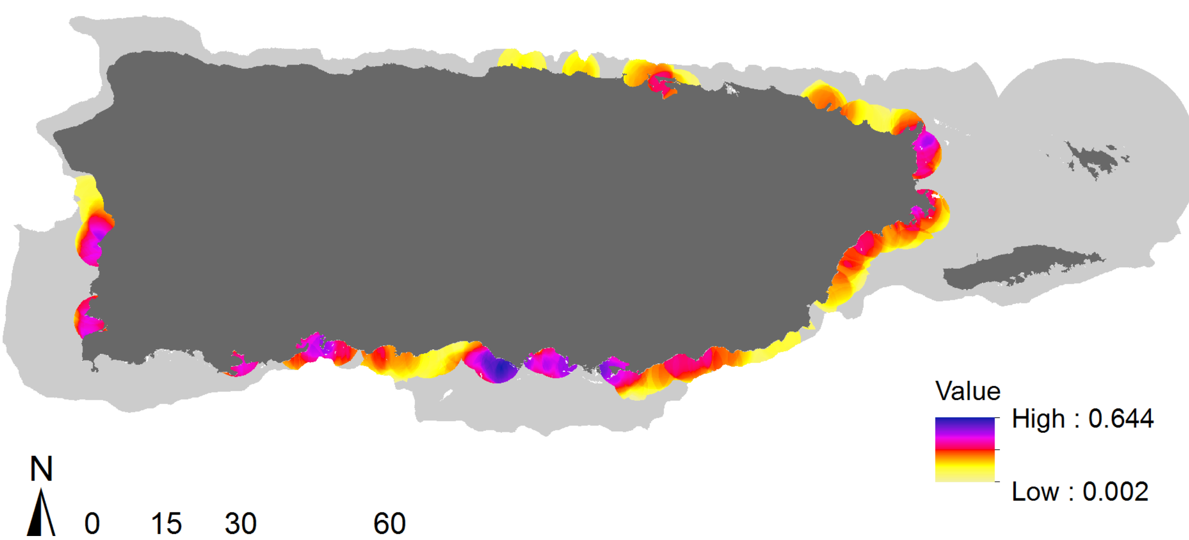


Figure 11. The calculated potential MPA value of coastal waters of Puerto Rico given the relative abundance (within a 5 km radius) of key ecological attributes (seagrass, freshwater, and shelter) and threats that can be mitigated through implementation of an MPA (motorized watercraft).

Using the 90th percentile (top 10%) threshold of MPA value to define regions led to the identification of 17 distinct regions, seven of which exceeded 1 km2 in area (Table 6; Figure 13A). The regions differ not only in size and overall MPA value but also in the relative value of the component variables and in whether the necessary resources are physically located within or external to (but within 5 km of) the region. The Santa Isabel West region was both the largest and the highest

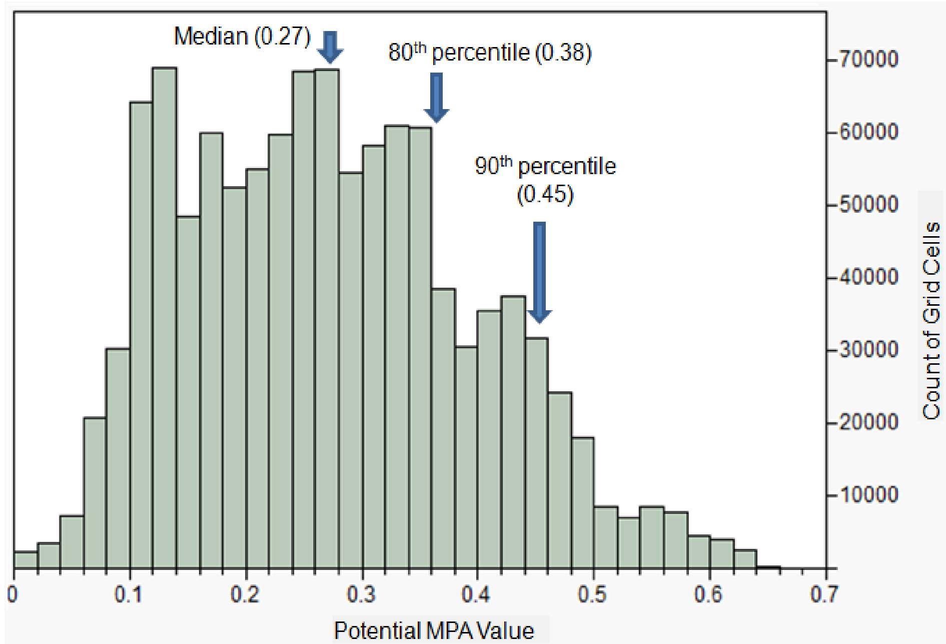


Figure 12. Histogram illustrating the distribution of calculated MPA Values (for grid cells > 0 value). Percentile cut-offs used to define regions of high potential MPA value. Maps of the 90th and 80th percentile regions are shown Figures 13A and 13B, respectively.

MPA valued region. This region also had the highest seagrass value among the 90th percentile regions. However, the Fajardo region presented the highest watercraft threat value, Mayagüez the highest freshwater value, and Guayanilla and Tallaboa the highest shelter value. Five of the regions did not include a mapped freshwater resource point within the region, but in each case freshwater resource points were present immediately outside the 90th percentile area. Three of the regions at least partially overlap existing stewardship areas.

Using the less conservative, 80th percentile (top 20%) threshold led to the identification of 27 regions, nine of which exceeded 1 km2 in area (Table 7; Figure 13B). The Santa Isabel West region again scored the highest MPA value and the highest seagrass value. The Guayanilla and Tallaboa region scored highest for freshwater and shelter value, while the Fajardo region scored highest for watercraft threat value. Three regions were near, but did not physically encompass, all required resources (Fajardo, Guánica, and Roosevelt Roads). Therefore, their boundaries would have to be modified if designated as an MPA site. Six regions (Santa Isabel West, Bahía de Rincón, Bahía de Jobos, Fajardo, Boquerón, and Guánica) at least partially overlapped waters with some form of stewardship designation (Table 7), but most of these designated waters are not actively managed under a conservation plan.

All potential MPA regions were located on the main island of Puerto Rico, not Vieques or Culebra. Furthermore, no potential MPA regions were identified on the north shore of Puerto Rico. Non-MPA regions scored lower for either (or both) resource value and threat value. The final nine 80th percentile regions are the set identified and discussed as Potential MPA Regions for the remainder of this report.

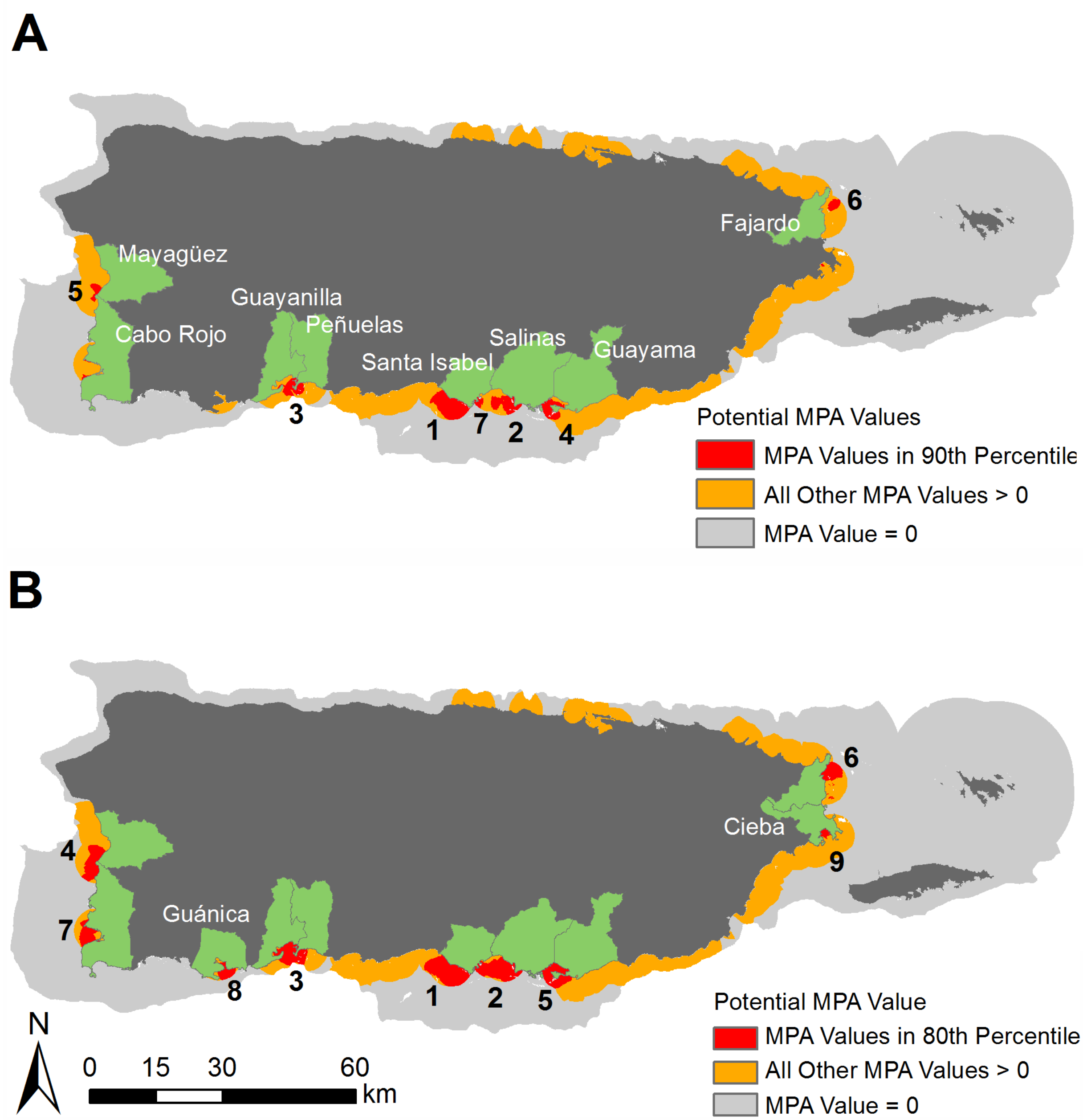


Figure 13. Potential MPA regions as delineated with a 90th (A) and 80th (B) percentile threshold value. Numbers correspond to Potential MPA Region name and summary information found in Tables 6 and 7. Municipalities bordering potential MPA regions are named (white text). All municipalities shown in A are also present in B but are not renamed in B due to space limits.

Table 6. Summary data of the seven 90th percentile MPA Value regions greater than 1 km² in area (Figure 13A). The regional average relative values of the threat (Boats) and key ecological attributes (Freshwater, Seagrass, and Shelter) are shown along with the actual number (or area, km²) of the threat and resource within the regional boundaries. The highest values are highlighted green. As value is defined based on exposure to threat (or access to resources) within 5 km, it is possible for the target threat (or resource) to lie outside but proximate to the MPA region (yellow boxes). Stewardship areas overlapping potential MPA regions are shown, but note that most stewardship areas are unmanaged marine jurisdictional extensions of terrestrial lands.

| | | | | Boats | | | Freshwater | | | Seagrass | | | Shelter | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Area | MPA Value | | Data Pts in Region | Value* | | Data Pts in Region | Value* | | Area in Region | Value* | | Area in Region | Value* | | |
| **Region Name** | km² | Mean | SD | | Mean | SD | | Mean | SD | | Mean | SD | | Mean | SD | **Existing Stewardship** |
| 1. Santa Isabel West | 33.5 | 0.552 | 0.046 | 7 | 0.360 | 0.055 | 1 | 0.755 | 0.101 | 25.4 | 0.778 | 0.111 | 17.5 | 0.452 | 0.058 | Reserva Natural Punta Petrona; Reserva Natural Isla Caja de Muertos |
| 2. Bahía de Rincón | 17.3 | 0.478 | 0.019 | 10 | 0.461 | 0.069 | 0 | 0.738 | 0.098 | 5.3 | 0.288 | 0.015 | 12.7 | 0.546 | 0.055 | None |
| 3. Guayanilla and Tallaboa | 13.1 | 0.470 | 0.016 | 2 | 0.222 | 0.032 | 0 | 0.800 | 0.075 | 3.4 | 0.310 | 0.021 | 8.3 | 0.905 | 0.074 | None |
| 4. Bahía de Jobos | 13.0 | 0.491 | 0.034 | 13 | 0.625 | 0.073 | 0 | 0.677 | 0.116 | 2.7 | 0.161 | 0.026 | 6.8 | 0.877 | 0.089 | Bahía de Jobos NERR |
| 5. Mayagüez | 5.4 | 0.467 | 0.015 | 4 | 0.520 | 0.049 | 1 | 0.873 | 0.053 | 2.2 | 0.678 | 0.063 | <0.1 | 0.156 | 0.016 | None |
| 6. Fajardo | 5.4 | 0.472 | 0.014 | 0 | 0.779 | 0.056 | 0 | 0.708 | 0.067 | 0.1 | 0.179 | 0.017 | 0.2 | 0.509 | 0.044 | None |
| 7. Santa Isabel East | 3.3 | 0.482 | 0.018 | 0 | 0.390 | 0.035 | 0 | 0.651 | 0.053 | 0.9 | 0.409 | 0.049 | 0.1 | 0.528 | 0.013 | Reserva Natural Punta Petrona |

**Mean of relative value of all pixels within the potential MPA region (0 to 1, where 1 = maximum value measured within the scope)*

Table 7. Summary data of the nine 80th percentile MPA Value regions greater than 1 km$^2$ in area (Figure 13B). The regional average relative values of the threat (Boats) and key ecological attributes (Freshwater, Seagrass, and Shelter) are shown along with the actual number (or area) of the threat and resource within the regional boundaries. The highest values are highlighted green. As value is defined based on exposure to threat (or access to resources) within 5 km, it is possible for the target threat (or resource) to lie outside but proximate to the MPA region (yellow boxes). The design of an MPA centered on these very small focal regions would have to incorporate these external resources. Stewardship areas overlapping potential MPA regions are shown, but note that most stewardship areas are unmanaged marine jurisdictional extensions of terrestrial lands.

| | | | | **Boats** | | | **Freshwater** | | | **Seagrass** | | | **Shelter** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Area** | **MPA Value** | | Data Pts in | Value* | | Data Pts in | Value* | | Area in | Value* | | Area in | Value* | | |
| **Region Name** | km$^2$ | Mean | SD | Region | Mean | SD | Region | Mean | SD | Region | Mean | SD | Region | Mean | SD | **Existing Stewardship** |
| 1. Santa Isabel West | 41.8 | 0.525 | 0.069 | 8 | 0.331 | 0.076 | 1 | 0.744 | 0.103 | 26.6 | 0.739 | 0.146 | 19.6 | 0.434 | 0.071 | Reserva Natural Punta Petrona; Reserva Natural Isla Caja de Muertos |
| 2. Bahía de Rincón | 34.4 | 0.455 | 0.034 | 12 | 0.402 | 0.088 | 1 | 0.731 | 0.106 | 7.0 | 0.298 | 0.049 | 18.0 | 0.511 | 0.060 | Reserva Natural Punta Petrona |
| 3. Guayanilla and Tallaboa | 24.4 | 0.447 | 0.031 | 9 | 0.199 | 0.046 | 4 | 0.809 | 0.104 | 5.8 | 0.297 | 0.032 | 13.4 | 0.868 | 0.099 | None |
| 4. Mayagüez | 23.5 | 0.428 | 0.027 | 7 | 0.452 | 0.085 | 1 | 0.799 | 0.093 | 12.5 | 0.687 | 0.130 | <0.01 | 0.146 | 0.019 | None |
| 5. Bahía de Jobos | 22.0 | 0.463 | 0.044 | 14 | 0.575 | 0.089 | 1 | 0.719 | 0.126 | 2.9 | 0.147 | 0.028 | 10.1 | 0.786 | 0.137 | Bahía de Jobos NERR; Bosque Estatal de Aguirre |
| 6. Fajardo | 14.7 | 0.438 | 0.031 | 11 | 0.729 | 0.087 | 0 | 0.730 | 0.099 | 0.5 | 0.156 | 0.024 | 2.1 | 0.455 | 0.067 | Reserva Natural Cabezas de San Juan |
| 7. Boquerón | 13.9 | 0.420 | 0.019 | 5 | 0.460 | 0.055 | 1 | 0.764 | 0.097 | 4.4 | 0.333 | 0.084 | 0.1 | 0.278 | 0.020 | Reserva Natural Punta Guaniquilla; Bosque de Boquerón |
| 8. Guánica | 8.9 | 0.409 | 0.013 | 6 | 0.575 | 0.053 | 0 | 0.657 | 0.083 | 1.9 | 0.168 | 0.007 | 3.4 | 0.448 | 0.020 | Bosque Estatal de Guánica |
| 9. Roosevelt Roads | 3.5 | 0.422 | 0.020 | 1 | 0.158 | 0.034 | 0 | 0.843 | 0.051 | 1.1 | 0.402 | 0.040 | 2.6 | 0.613 | 0.019 | None |

**Average relative value within the potential MPA region (0 to 1, where 1 = maximum value measured within the scope)*

## 4.4 Model Assessment

Experts provided valuable feedback throughout model development (Appendix 2). We presented the methods and results to three mixed audiences of participating and external experts March 22, 2011 at USFWS Caribbean Field Office in Boquerón, May 5, 2011 at the PRDENR office in San Juan, and May 25, 2011 at the USGS Sirenia Project office in Gainesville, FL (Appendix 1). All audiences identified minor biases or unexpected results in each of the component models (seagrass, freshwater, shelter, and watercraft). Overall, however, they felt the model input and output reasonably reflected their knowledge of manatee distribution and watercraft threats.

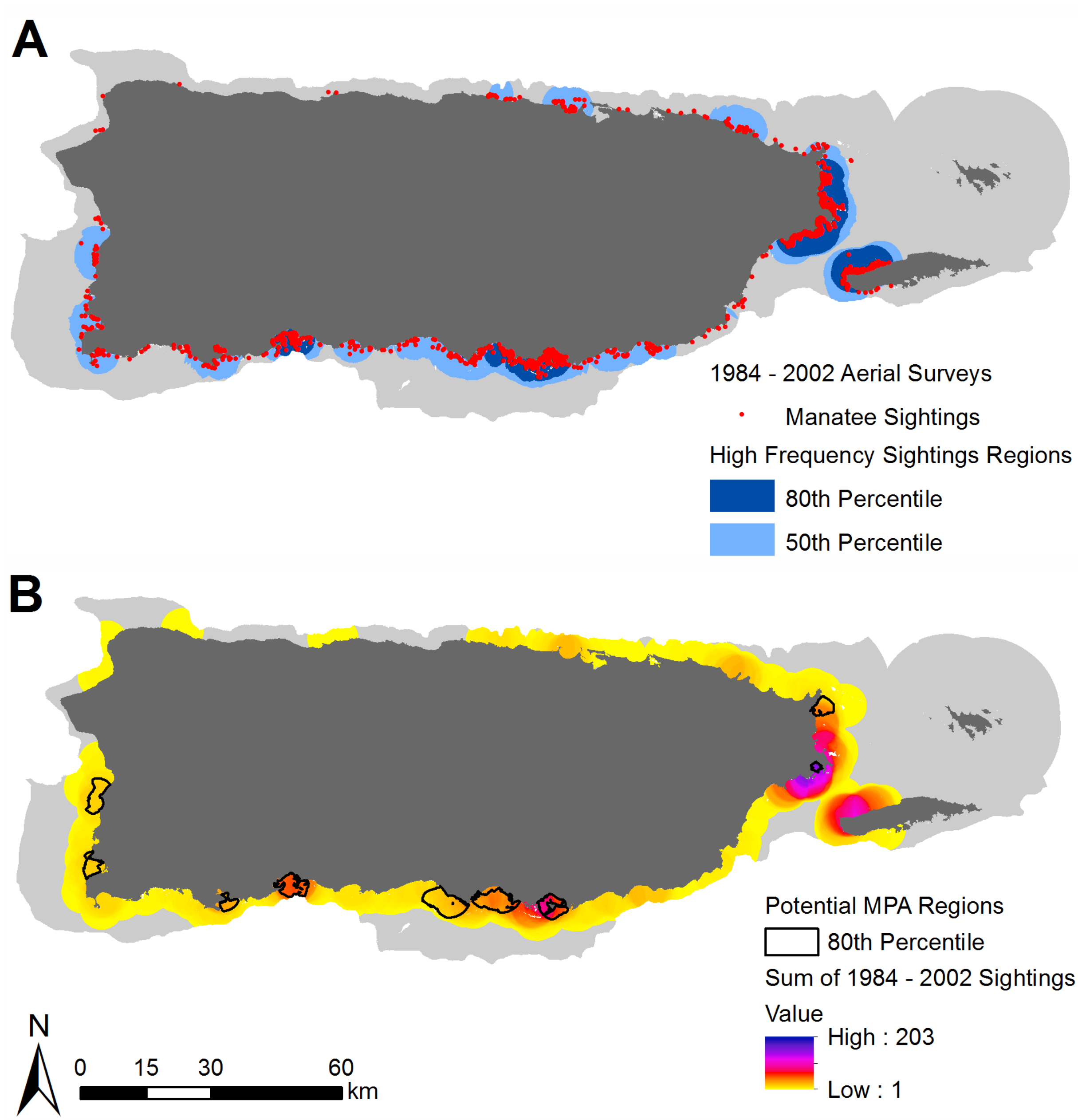


Figure 14. Comparison of 1984 – 2002 manatee 50th and 80th percentile "hotspots" (e.g., regions with a high density of manatee observations) during aerial surveys (A) and the modeled potential MPA regions (B). Light gray regions have zero manatee observations.

4.4.1 Comparison of MPA value and aerial sightings

Overall, the potential MPA regions overlapped with regions of high numbers of manatee observations (upper 50th percentile for number of manatees observed) during island-wide aerial surveys from 1984 to 2002 (USFWS, unpublished data; Figure 14A). Five of the nine potential MPA regions intersect (Figure 14B) with manatee "hotspots" (80th percentile for number of manatees observed; Figure 14A). These potential MPA regions were: Bahía de Jobos, Fajardo, Guánica, Guayanilla and Tallaboa, and Roosevelt Roads. The only 80th percentile observational hotspot that failed to be identified as a potential MPA region was the northwest coast of Vieques.

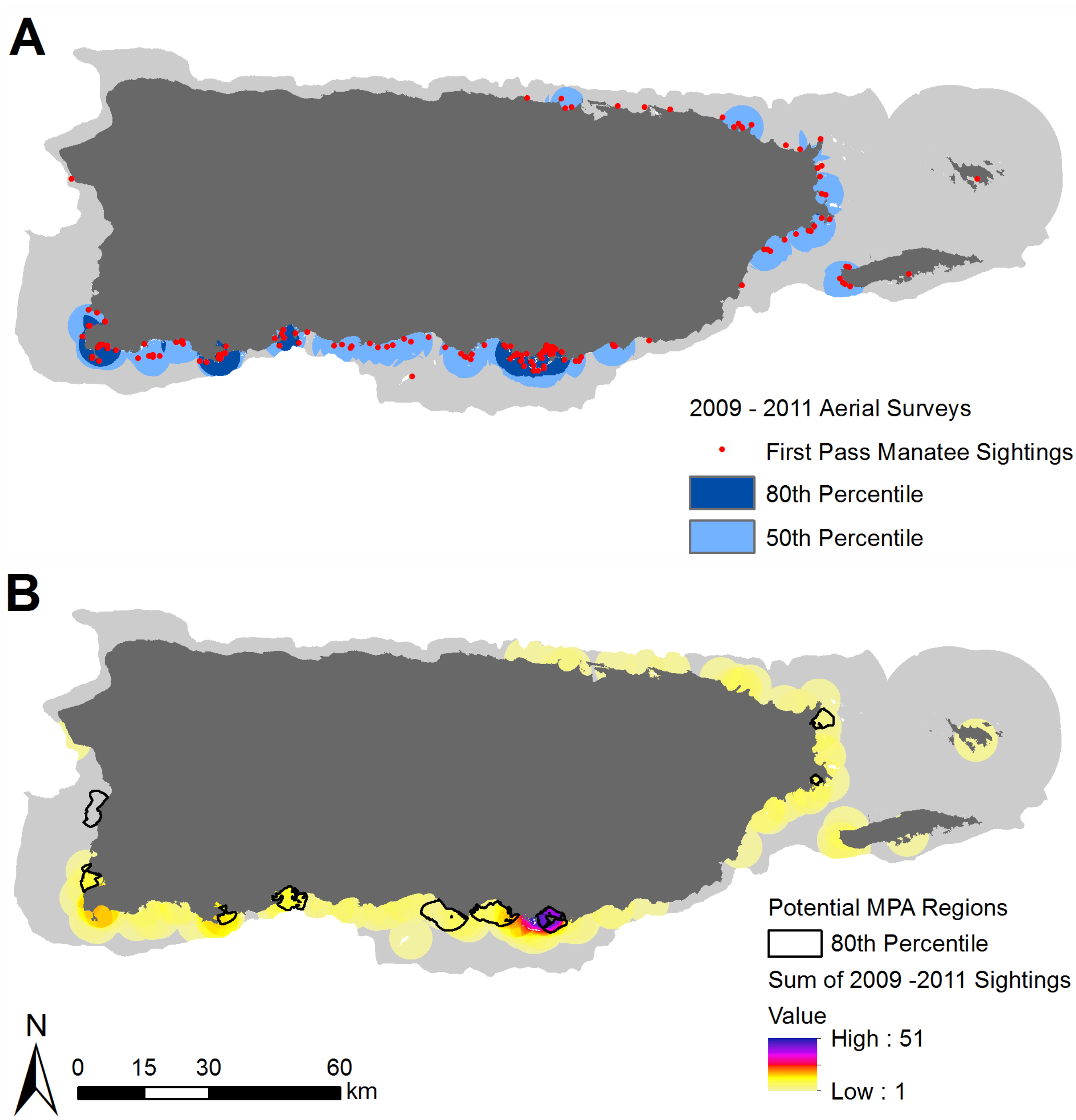


Figure 15. Comparison of 2009 – 2011 manatee 50th and 80th percentile "hotspots" (e.g., regions with a high density of manatee observations) during aerial surveys (A), and the modeled potential MPA regions (B). These data only include observations made in the first pass to ensure the data reflect equal sampling effort throughout the region. Light gray areas have zero manatee observations.

We also evaluated the potential MPA regions against aerial sighting made under the new survey protocols (USFWS, unpublished data; Figure 15A). To ensure the distribution of observations reflected roughly equal survey effort throughout the scope, we used just the first pass (flight) of data (additional passes were made over some areas when manatees were sighted under the new protocols). As these surveys have only run 2009-2011, the data are still sparse and most areas have few observations. Only five potential MPA regions (Figure 15A&B) also stand out as manatee observation hotspots (80th percentile for number of manatees observed): Bahía Boquerón, Guánica, Guayanilla and Tallaboa, Bahía de Rincón, and Bahía de Jobos.

4.4.2 Comparison of MPA value and mortality data

The modeled watercraft threat generally captured spatial trends in the mortality data (Figure 16). All eight manatee mortality events positively attributed to watercraft collision between 2000 and 2010 (PRDENR, unpublished data) occurred in the vicinity of the highest watercraft threat values. Looking at historical records (Mignucci-Giannoni et al. 2000), mortality events have been documented in the vicinity of all potential MPA regions except Mayagüez. Two areas noted high for overall mortality in the historical data that were not captured by our watercraft threat model were in the vicinity of the Río Grande in the northeast and Guayanilla in the south. These mortality data must be considered in light of the fact that Puerto Rico's generally open coastlines may increase the chances that a carcass would be washed to sea and reduce the probability of carcass recovery.

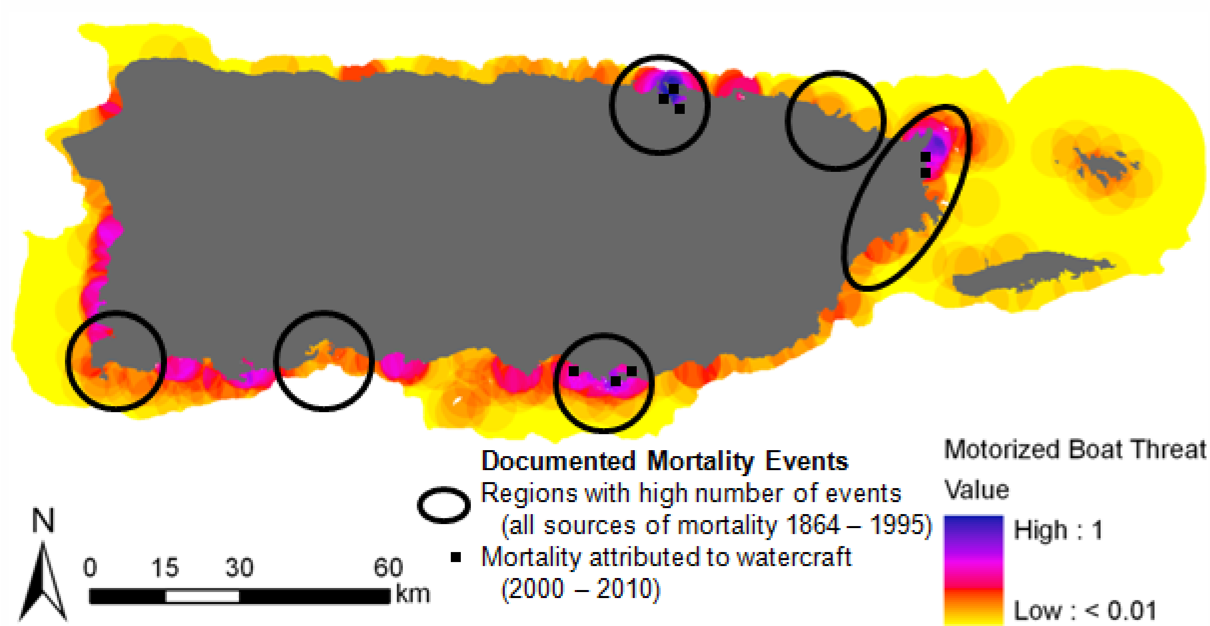


Figure 16. Comparison of regions historically reporting high number of mortality events (black circles, as shown in Mignucci-Gianonni et al. 2000), locations of recent watercraft related mortality events (black squares; PRDENR, unpublished data), and modeled watercraft threat.

## 5. POTENTIAL MPA REGIONAL SUMMARIES

The regions are presented here in order of increasing total area to facilitate comparison with Table 7. Given that each potential MPA region contains a broad range of MPA values (but always MPA values within the 80th percentile), we recommend all equally for consideration by the USFWS. Manatees have been observed in all potential MPA regions (USFWS, unpublished data). This section summarizes published data and observations relevant to each potential MPA region in turn to note overlap with high density or frequency of manatee use (i.e., hotspots), local resource use patterns, known mortality events, or existing manatee management actions.

### 5.1 Region 1: Santa Isabel West

Figure 17

No published documents obtained through the course of this study directly referenced the western shore of Santa Isabel as a manatee hotspot.

### 5.2 Region 2: Bahía de Rincón

Figure 18

No published documents obtained through the course of this study directly referenced the Bahía de Rincón as a manatee hotspot.

### 5.3 Region 3: Guayanilla and Tallaboa

Figure 19

Powell (1981) observed manatees in Bahía Guayanilla on seven of ten island-wide surveys conducted between 1976 and 1979. Similarly, island-wide aerial surveys conducted monthly from 1984 and 1985 identified the Guayanilla region as one of several manatee hotspots (Rathbun et al. 1985).

Marine mammal and sea turtle aerial surveys of the southwest coastline of Puerto Rico conducted for Eco-Electrica from 2000 to 2005 (Mignucci-Giannoni et al. 2006) provide descriptions of manatee distribution within these waters. Although manatees were observed throughout the entire survey region from Cabo Rojo to Ponce, several clusters of repeated sightings were noted. Clusters observed in and near this potential MPA region occurred at: Punta Verraco, both sides of Punta Guayanilla, and the cayos Caribe, Palomas, Río and María Langa. The largest concentration of manatees observed together during this series of thirteen surveys occurred in the region between Cayo María Langa and Cayo Caribe.

A survey of manatee habitat use within Bahía Guayanilla used telemetry to regionally track seven manatees (USGS, unpublished data; cited in Reid 2007). Movements of three adult females from this group were analyzed in relation to the establishment of a thermal lagoon in the eastern portion of the bay by Eco-Electrica (Reid 2007). Manatees did visit the thermal lagoon, but usually for less than six hours in what were hypothesized to be resting or milling bouts, as they primarily remained with the center of the lagoon where aquatic vegetation was absent. Manatee movement patterns may indicate that the wastewater treatment discharge into the lagoon, which is mixed with saline water, was utilized as a source of freshwater. Outside the thermal lagoon, but still within Bahía Guayanilla, the individual manatees differed in their habitat use patterns. One individual primarily remained within the inner bay, while the other two used Punta Verraco and the outer portions of the bay extensively. Use of the thermal lagoon was hypothesized to be incidental to their overall use of the bay (Reid 2007). Bahía Guayanilla served as one of several capture and release sites in a telemetry study of manatee distribution and habitat use (Slone et al. 2006). Although individual manatees often ranged broadly, Bahía Guayanilla was one region where manatees would exhibit more restricted movements. Manatees were observed to regularly use both the Río Guayanilla and the Río Yauco as freshwater resources (Slone et al. 2006).

### 5.4 Region 4: Mayagüez

Figure 20

The Río Guanajibo, lying on the southern edge of this potential MPA region is one of the few rivers in Puerto Rico that periodically have enough water to allow manatees to enter and move upstream (Powell 1981). This river has been noted as an important resource to manatees in several reports (Powell 1981; Lefebvre 2001). Powell (1981) noted that the importance of Río Guanajibo and Mayagüez region could be easily overlooked as heavy siltation from the river greatly reduced the effectiveness of aerial surveys.

In August 1997, two female manatees captured in the mouth of Río Guanajibo were fitted with radio belts and tracked as they utilized habitats along the south part of the west coast and along the south coast as far as La Parguera and Guánica during fall of 1997 (Mignucci-Giannoni et al. 2006). One of these two individuals was resighted with a calf off Cabo Rojo in November 2001 (Mignucci-Giannoni et al. 2006).

Bahía Guanajibo served as one of several capture and release sites in a telemetry study of manatee distribution and habitat use (Slone et al. 2006). A male manatee captured and tagged in Guanajibo travelled north and east nearly as far as San Juan before returning to Guanajibo. However, such long distance travel, though possible, was not common. However, it was common for animals to travel between Guanajibo and Bahía de Boquerón, with some individuals also travelling around Punta Jagüey to La Parguera and Guánica. The Río Guanajibo was one of several rivers around the island regularly used as a freshwater resource by radio tagged manatees. Habitats at the mouth of the river and extensive seagrass beds south of Punta Guanajibo were also heavily used.

### 5.5 Region 5: Bahía de Jobos

Figure 21

Island-wide aerial surveys conducted monthly from 1984 to 1985 identified Bahía de Jobos as one of several manatee hotspots (Rathbun et al. 1985). Manatees are commonly observed in the seagrass beds of the Bahía de Jobos National Estuarine Research Reserve (PRDNER 2010b). The reserve's 2010-2015 management plan incorporates conservation practices directed to positively influence manatees, which the plan claims are found in greatest numbers in Bahía de Jobos. The management plan summarizes the extent of seagrass resources locally:

> "The seagrass beds cover approximately 70 percent of the shallow (9 ft, < 3 m) substrata in Jobos Bay, and about 30 percent in deeper areas down to 30 ft (10 meters) (PWRA 1972). These meadows occupy most of the shallow bottoms just offshore from the mangrove fringe. Dense beds of *Thalassia* are also present in the semi-enclosed areas of Jobos Bay with good circulation and clear water."

Proposed management actions include buffer zones for manatee high use areas and a navigation channel established for boats coming in and out of the eastern side of Bahía de Jobos (PRDNER 2010b).

The principal streams in this potential MPA region are intermittent, only flowing at certain times of the year. Several only flow during extreme rainfall events (Kuniansky and Rodriguez 2010). Therefore, to obtain freshwater, manatees in Bahía de Jobos must travel outside the bay, depend upon freshwater (if present) in the thermal outflow pipe in the bay, access groundwater resources (if present), or opportunistically use the bay when rains have filled the intermittent streams. Groundwater flow to the mangrove regions surrounding the bay is significant, but considered threatened by current land use and water use practices (Kuniansky and Rodriguez 2010).

### 5.6 Region 6: Fajardo

Figure 22

No published documents obtained through the course of this study directly referenced this region as a manatee hotspot. However, the Río Fajardo lies immediately to the south and is a well-known source of freshwater for manatees (Powell 1981).

### 5.7 Region 7: Boquerón

Figure 23

Bahía de Boquerón served as one of several capture and release sites in a telemetry study of manatee distribution and habitat use (Slone et al. 2006). Both Puerto Real (immediately north) and Bahía de Boquerón were identified as heavy use areas by the tagged manatees.

### 5.8 Region 8: Guánica

Figure 24

Mignucci-Giannoni et al. (2006) noted that the Río Loco, on the northwest coastline of Bahía de Guánica, may be the most important freshwater resource between Cabo Rojo and Ponce. The coastline of the Guánica municipality had the most frequent manatee sightings during aerial surveys of any region surveyed (29% as one of six municipalities). Notable sightings included mating groups on two of thirteen surveys. Guánica municipality also had more mother-calf pair sightings (28.8%) than any of the other five municipalities. Slone et al. (2006) also noted the regional importance of Guánica. Some manatees tagged in Guayanilla repeatedly traveled to Guánica. Likewise, tagged manatees using La Pargüera also traveled to Guánica and the Río Loco to access freshwater. In Guánica, they made heavy use of the Bahía de Guánica and the coastline near Montalva. These reports reaffirm Rathbun et al. (1985) identification of Guánica as a hotspot.

### 5.9 Region 9: Roosevelt Roads

Figure 25

Manatees have been documented drinking from the former naval station's wastewater treatment plant outflow pipe at Cape Hart (20.6 ± 12.6 individuals per hour from 1984 to 1985: Rathbun et al. 1985), but not at Forrestal or Bundy outflows (Powell et al. 1981; Rathbun et al. 1985; Lefebvre et al. 2001). Describing manatee use of the Cape Hart outflow, GeoMarine Inc. (2004) reported:

> "Manatees principally used the outer effluent (150 m from shore) during the first five months of observations (May through September 1984) and then switched to the inner effluent (50 m from shore) during the last five months of surveys (October 1984 through February 1985). Over 80% of the sightings in the Cape Hart area occurred within a 10-m radius of each outfall and along a 20-m corridor between the two effluents. When manatees approached the effluent, they swam directly to the pipe opening and stuck their heads in for 0.5 to 3.5 minutes (Rathbun et al. 1985)."

These plants had been proposed to receive reduced flow, or possibly cessation of flow, when the naval station closed in 2004 (GeoMarine Inc. 2004). However, they remain in operation (J. Zegarra, USFWS, personal communication) as the plan to transition ownership of the naval properties remains in review (U.S. Department of the Navy 2011). The interim proposed action was to reduce flows by 77% at the Bundy plant, 31.38% at the Cape Hart plant, and 66.78% at the Forrestal plant. Given the abundance of alternative regional freshwater resources frequented by manatees (e.g., ríos Fajardo, Daguao, Blanco and Humacao), GeoMarine Inc. (2004) concluded that reducing or eliminating wastewater flow would not have any long-term negative impacts on manatees.

The NAPR (Naval Activity Puerto Rico) report (GeoMarine Inc. 2004) also identified several shallow, sheltered bays where manatees frequently forage: Pelican Cove and Ensenada Honda are two seagrass-laden areas where feeding manatees are most often spotted (Rathbun et al. 1985; Freeman and Quintero 1990; Lefebvre et al. 2000). Manatees also frequently utilize seagrass bed habitats in Bahía Algodones and nearby waters located along the southern perimeter of NSRR (Reid 1994).

The Cape Hart outflow and other regions within the Roosevelt Roads potential MPA region served as one of several capture and release sites in a telemetry study of manatee distribution and habitat use (Slone et al. 2006). Although individual manatees often ranged broadly, Ensenada Honda was one region where manatees would exhibit more restricted movements (Slone et al. 2006). Again in this study, manatees were observed to regularly drink from the Cape Hart outflow. Within the vicinity of this potential MPA region, manatees heavily used Bahía de Puerca, the southwest coast of Ensenada Honda, and Bahía Algodones.

Lefebvre et al. (2000) also captured and tagged manatees in the vicinity of RRNS and tracked their habitat use in RRNS and the north shore of Vieques. Their results concur with other studies. Manatees made heavy use of seagrass beds and coastal waters of Ensenada Honda and the various shallow, sheltered coves and bays. They noted that some manatees appeared to selectively seek out and forage in the *H. wrightii* beds within and to the east of Pelican Cove, which were higher energy environments than typically associated with foraging behaviors. Manatees also frequently foraged in portions of Bundy Cove and Bahía Algodones, which offered *T. testudinum* beds containing the calcareous algae *Halimeda optunia*.

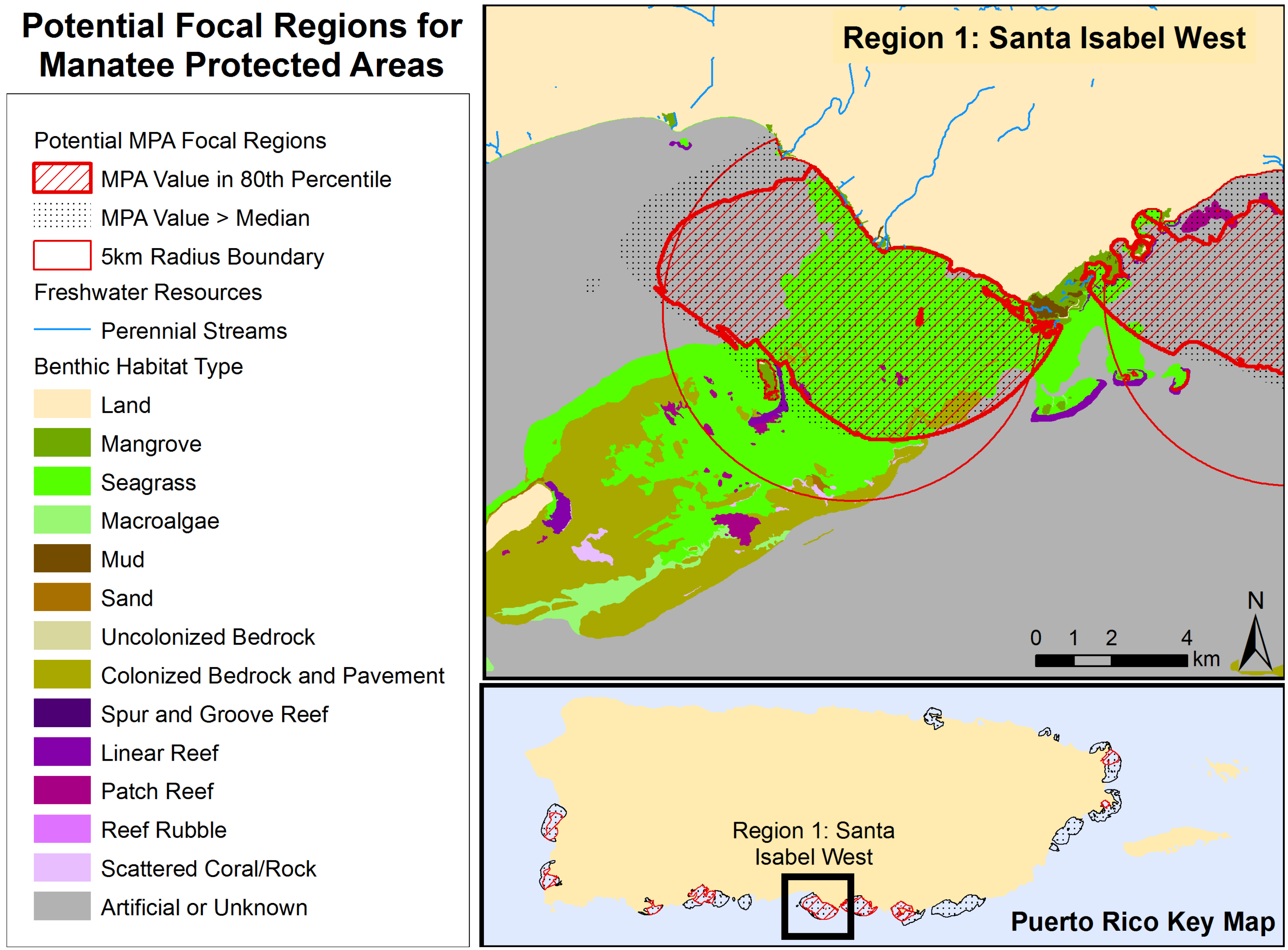


Figure 17: Potential MPA region encompassing coastal waters west of Santa Isabel. No landmarks within this region were specifically named in association with published manatee observations.

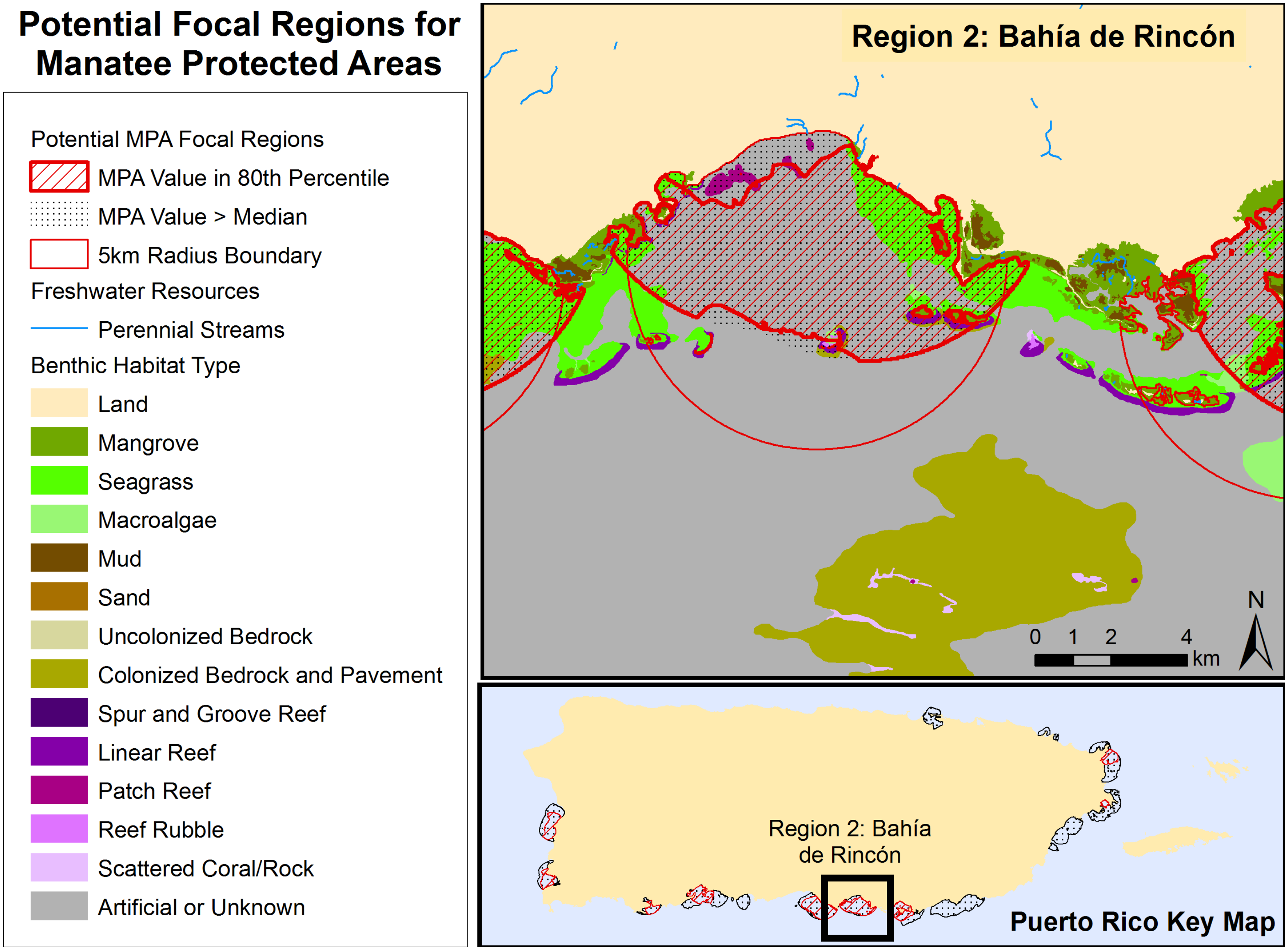


Figure 18: Potential MPA region encompassing coastal waters in Bahía de Rincón. No landmarks within this bay were specifically named in association with published manatee observations.

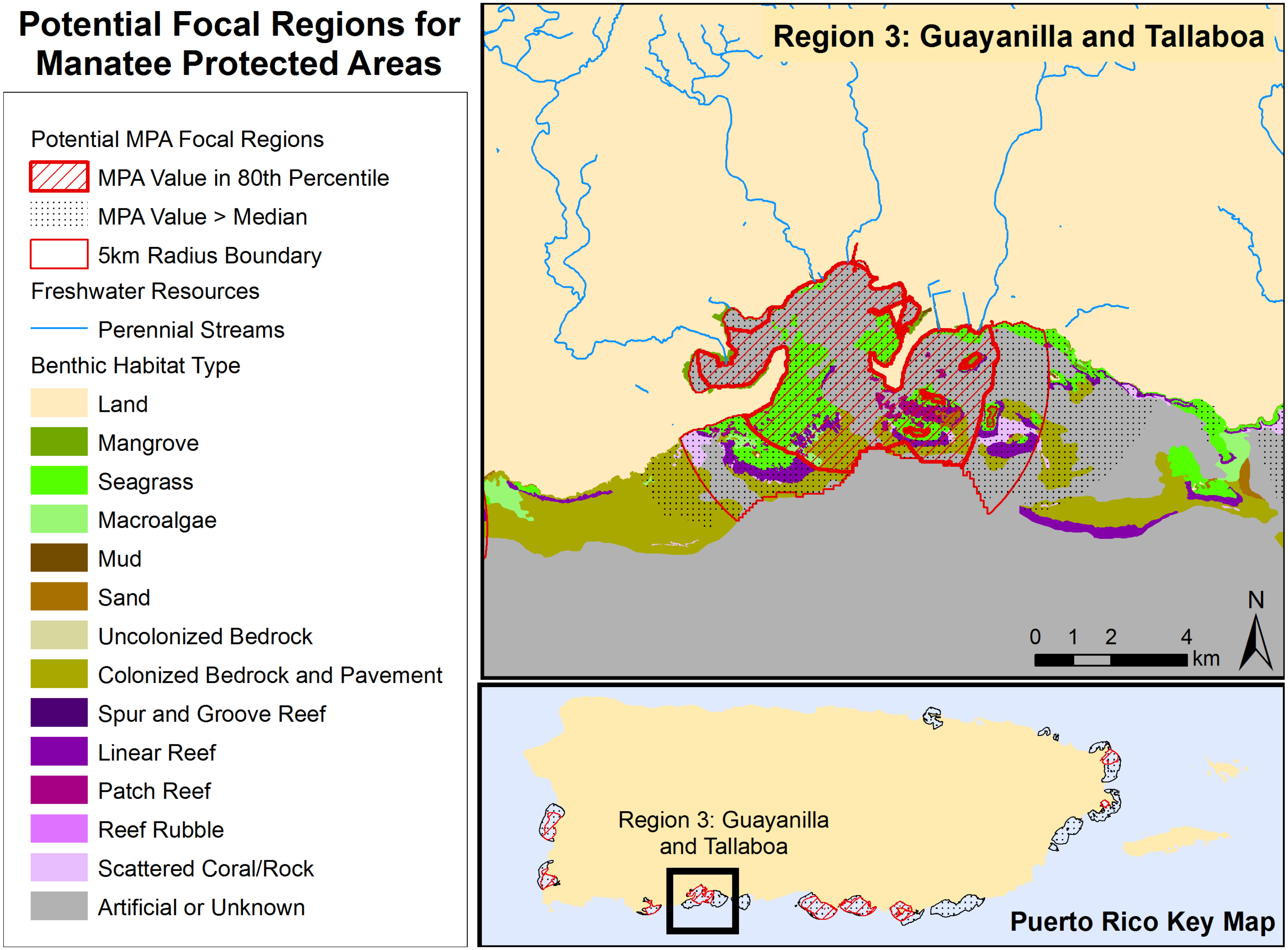


Figure 19: Potential MPA region encompassing coastal waters of Guayanilla and Tallaboa. Landmarks named on map are features associated with published manatee observations.

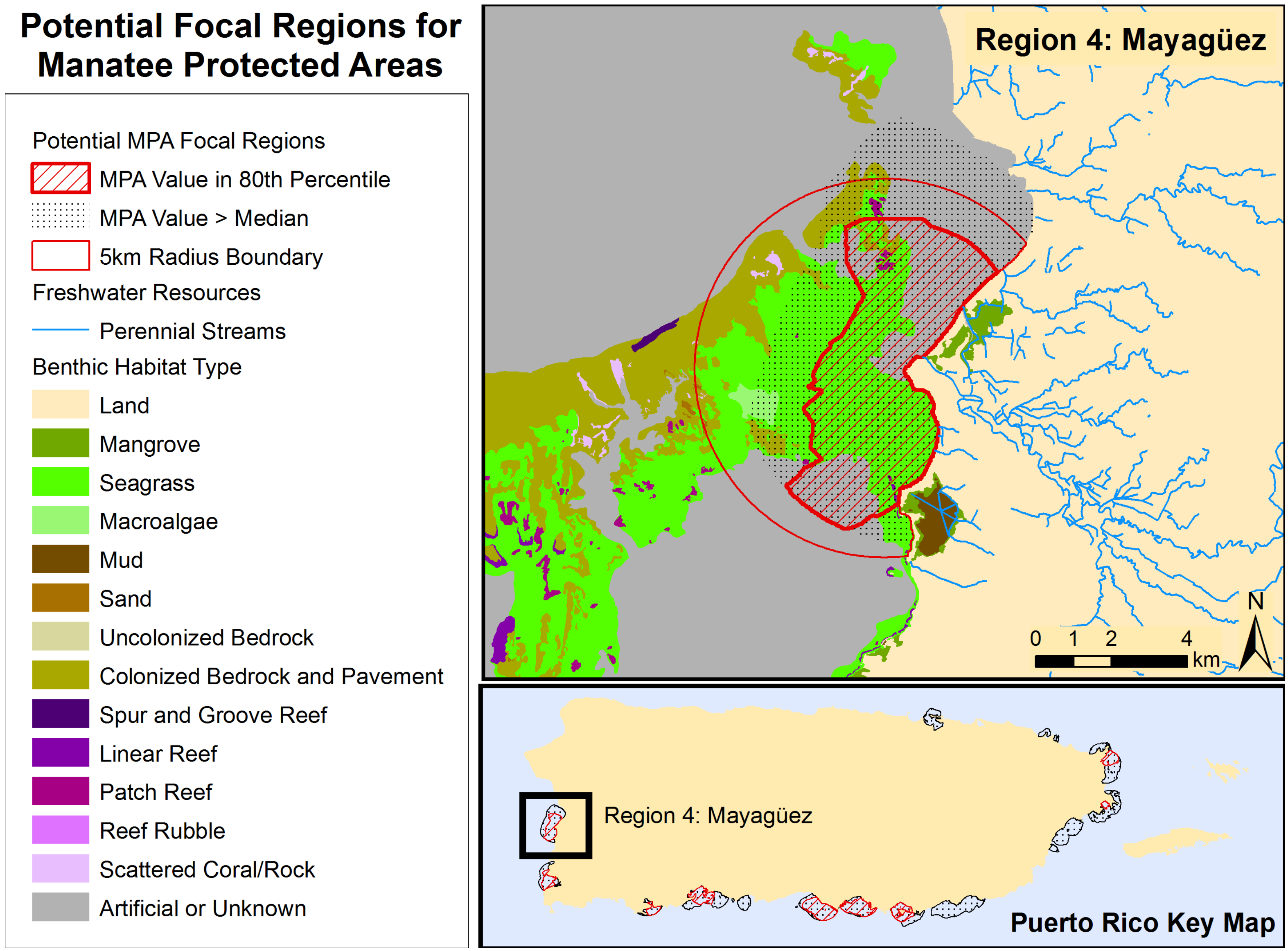


Figure 20: Potential MPA region encompassing coastal waters of Mayagüez. Landmarks named on map are features associated with published manatee observations.

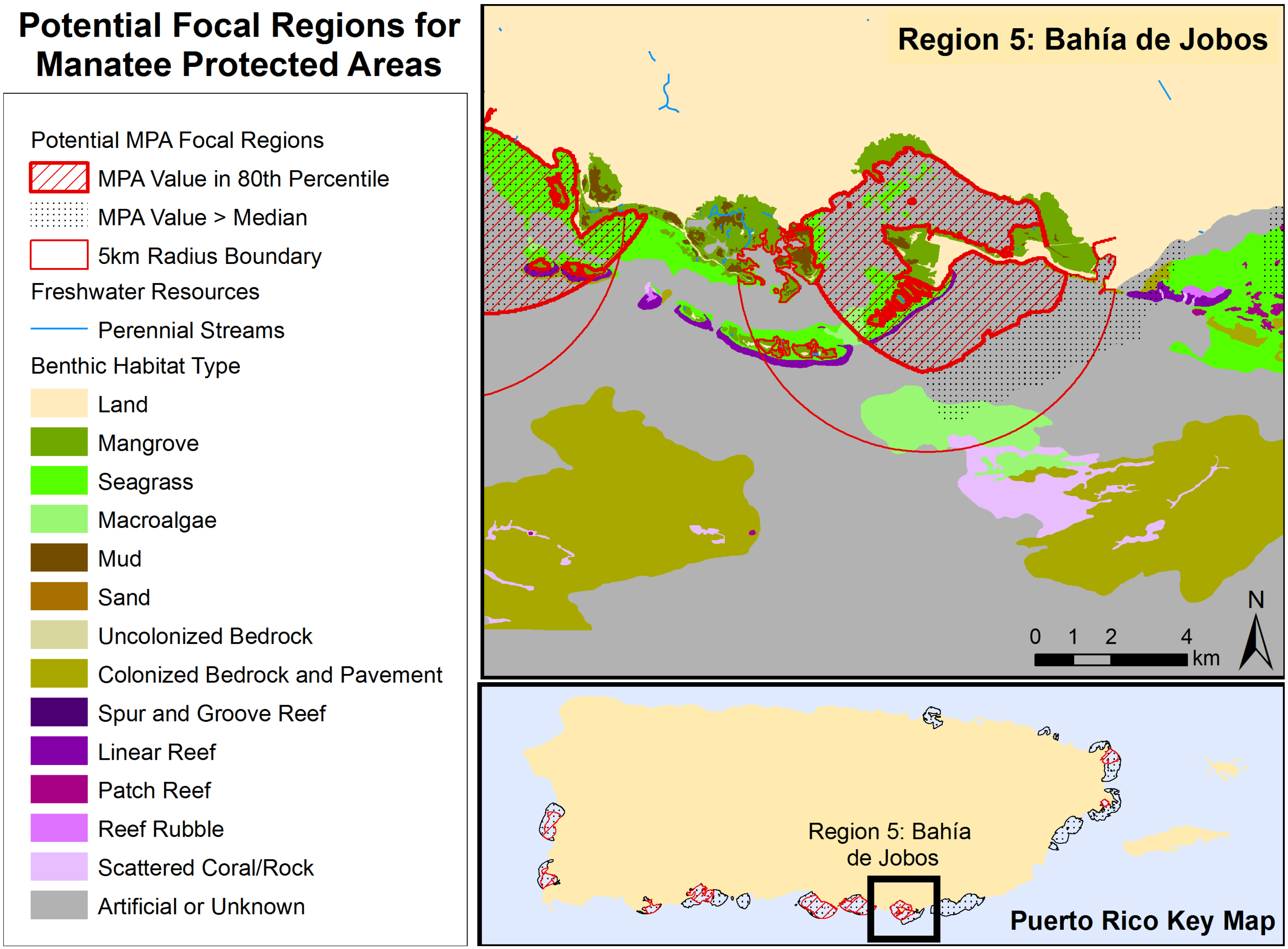


Figure 21: Potential MPA region encompassing coastal waters west of Bahía de Jobos. Landmarks named on map are features associated with published manatee observations.

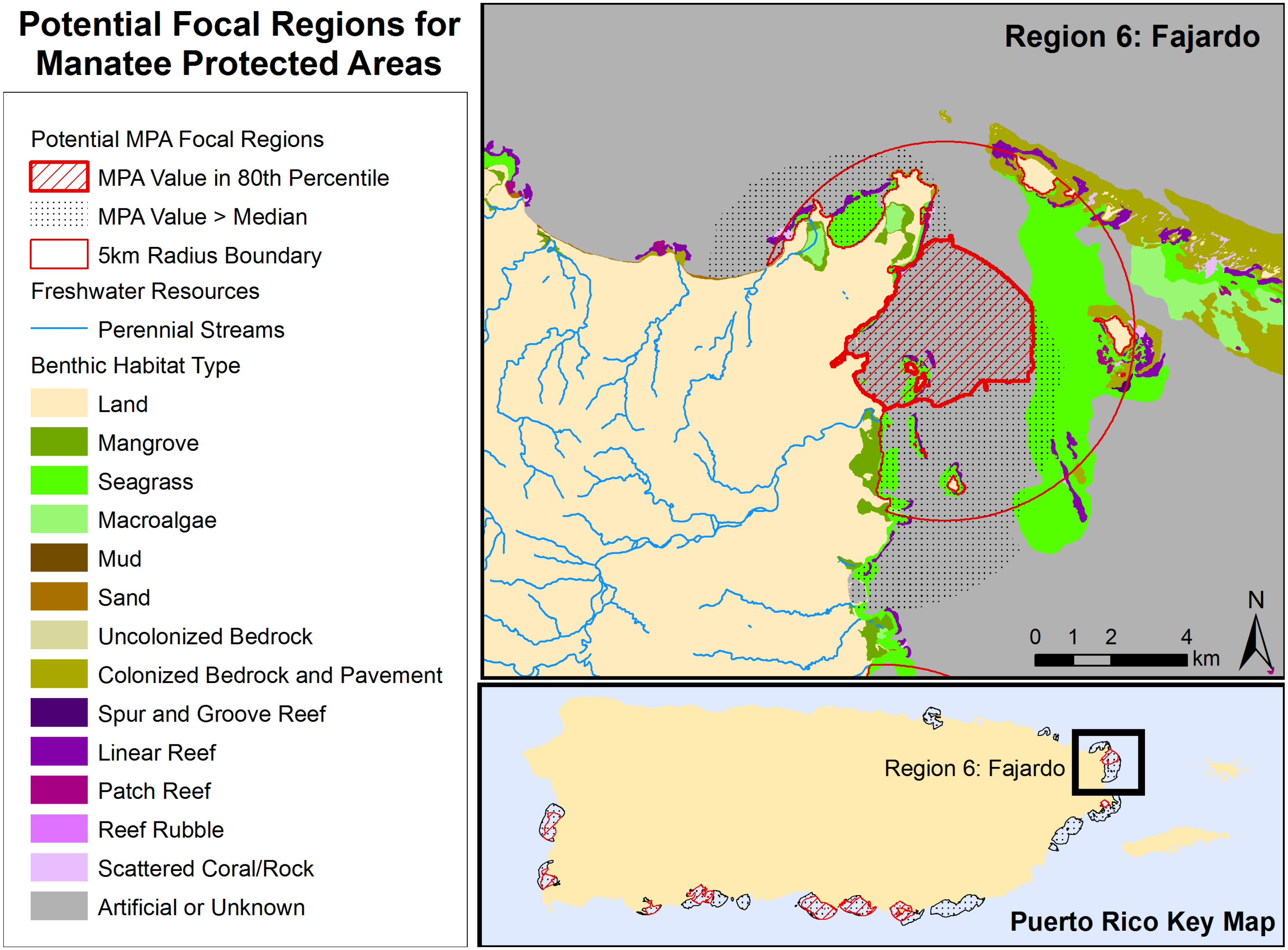


Figure 22: Potential MPA region encompassing coastal waters near Fajardo. Landmarks named on map are features associated with published manatee observations.

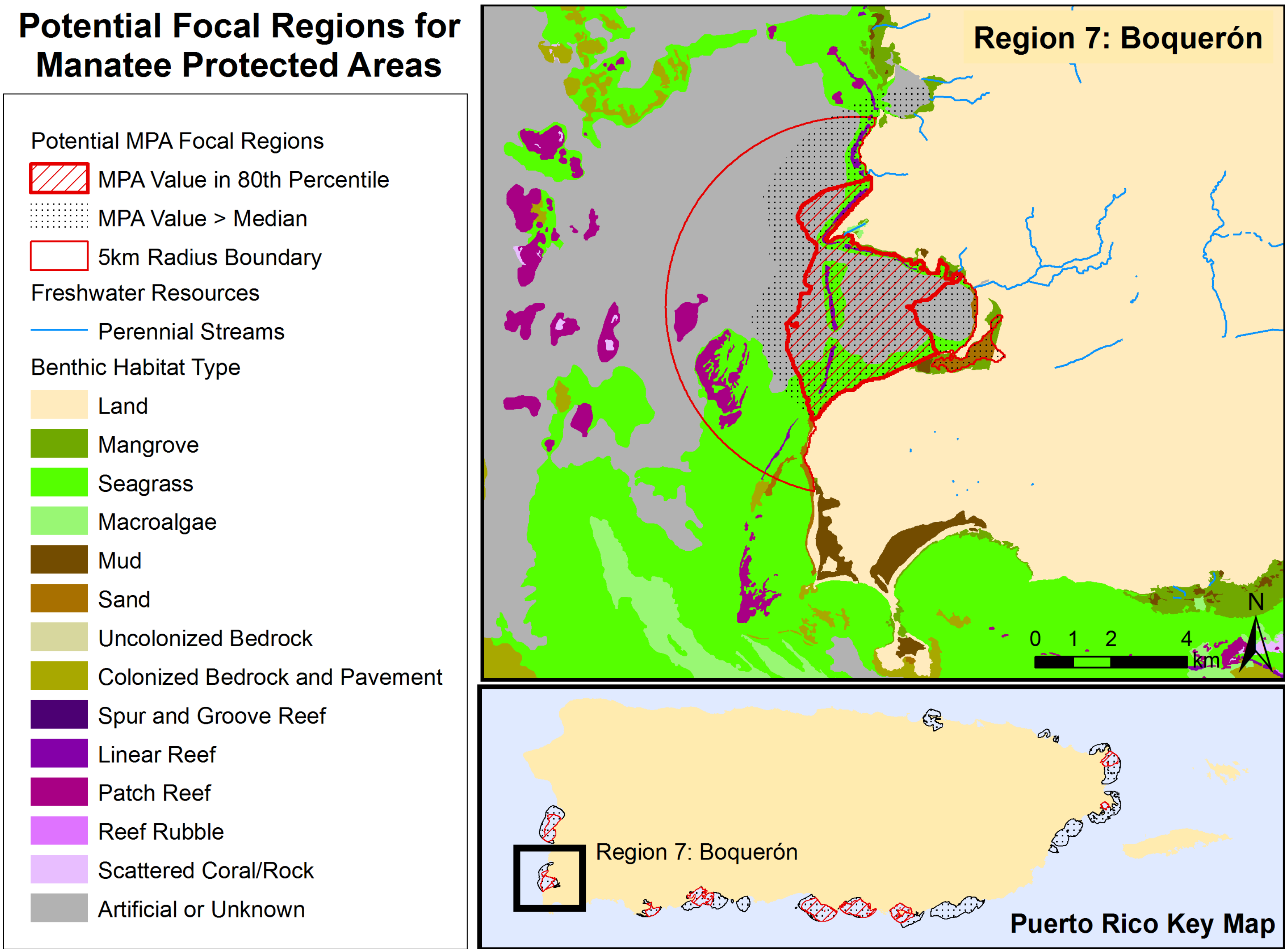


Figure 23: Potential MPA region encompassing coastal waters of Boquerón. Landmarks named on map are features associated with published manatee observations.

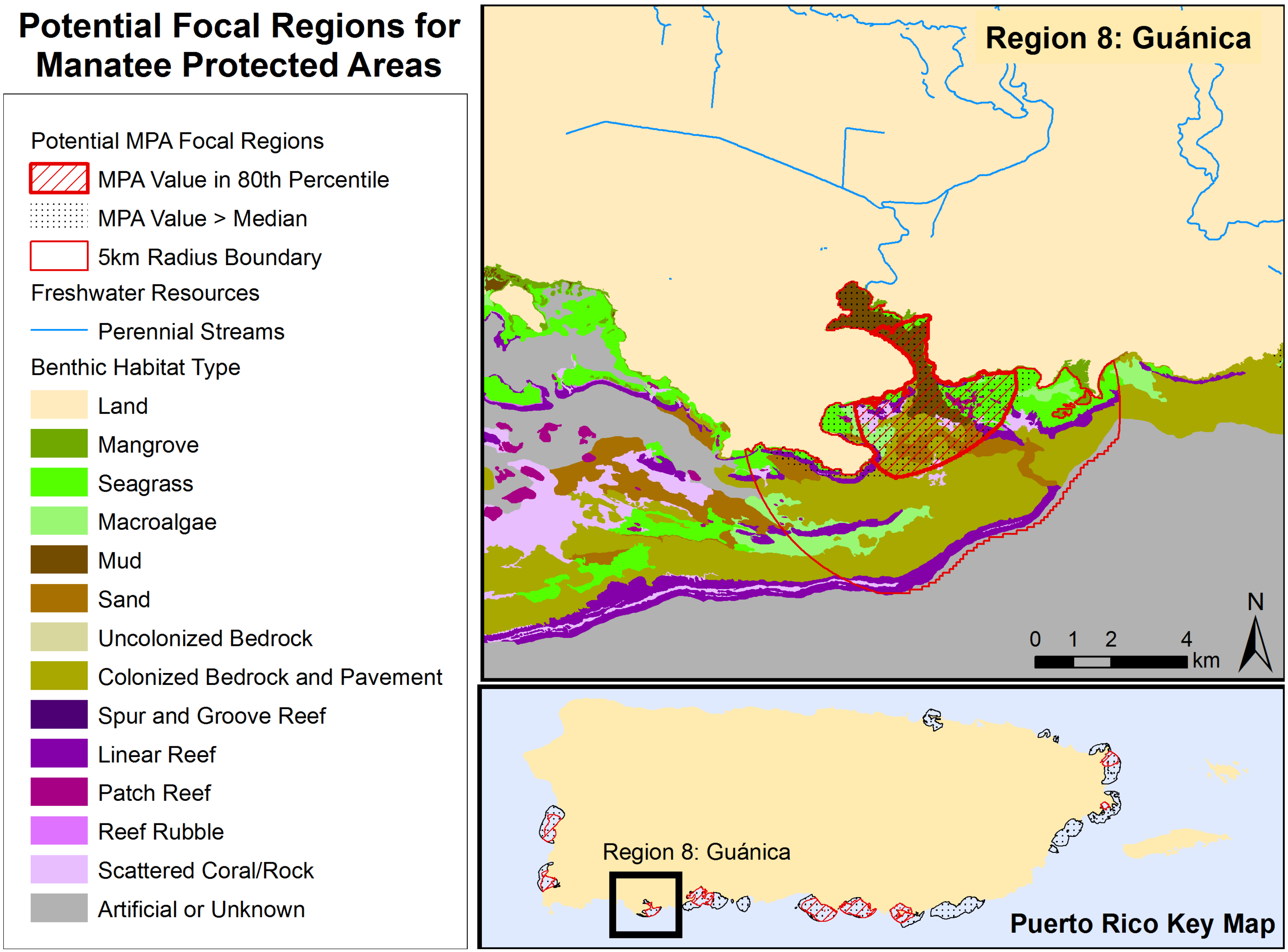


Figure 24: Potential MPA region encompassing coastal waters of Guánica. Landmarks named on map are features associated with published manatee observations.

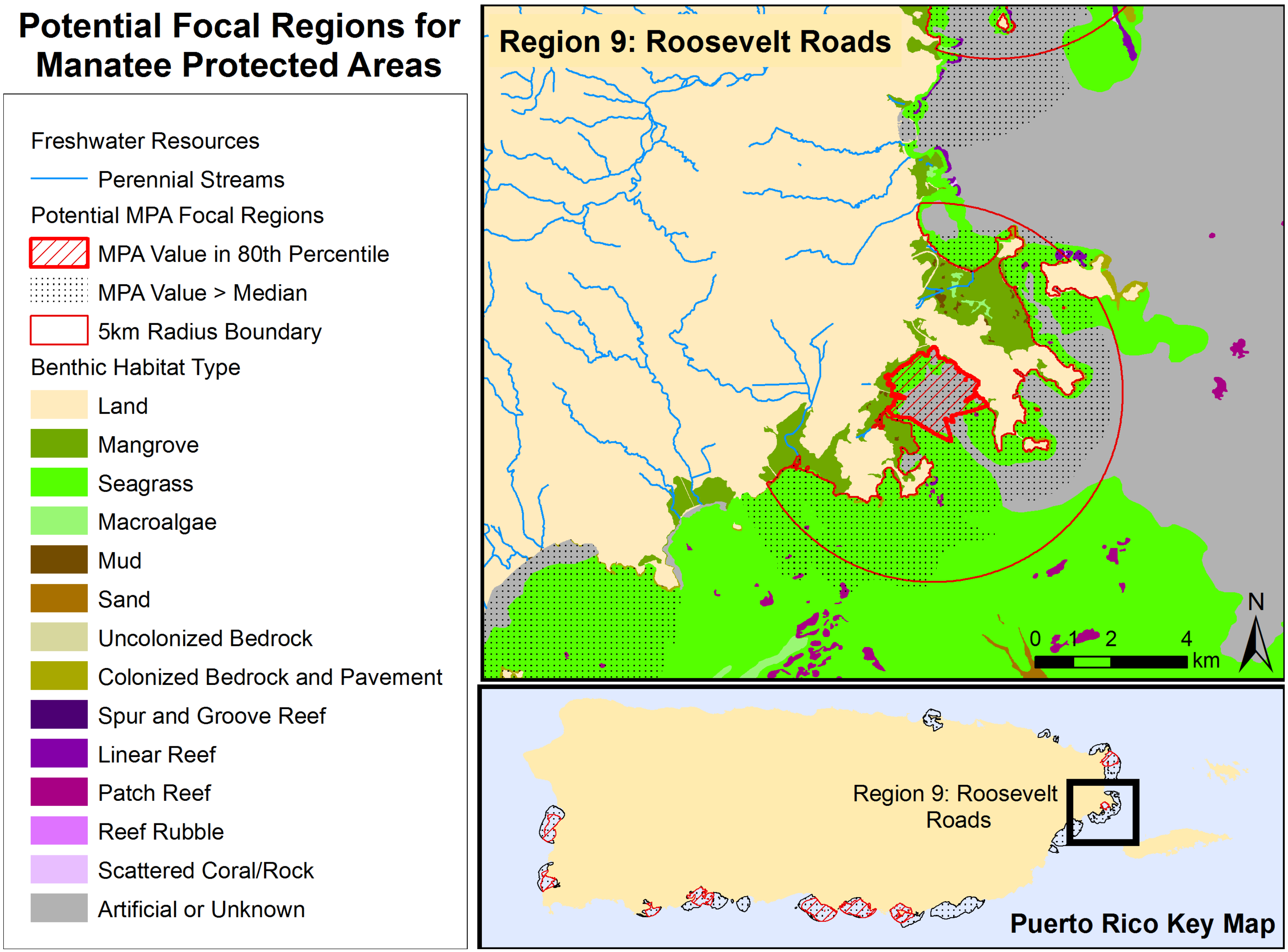


Figure 25: Potential MPA region encompassing coastal waters of the former Roosevelt Roads Naval Station. Landmarks named on map are features associated with published manatee observations.

## 6. DISCUSSION

The potential MPA regions highlighted in this report represent sites where manatee key ecological attributes and threat from motorized watercraft overlap. Given expert hypotheses and available spatial data, these regions offer the greatest opportunity to potentially reduce take through management of motorized watercraft activities and reduce manatee population disturbance. All potential regions should be considered equally, as all represent regions where MPA values are in the 80th percentile. Below, we recommend next steps in the MPA design process, outline expert input regarding measures of success, and reiterate some of the major hypotheses and assumptions underlying the model.

### 6.1 Recommended Steps to Narrow MPA Region Selection

This report identifies and compares a series of potential MPA regions based on remotely sensed and modeled habitat characteristics and watercraft threat. Prior to selecting one or more regions for protection, several factors should be considered. First, we recommend the results (presence of abundant resources and high watercraft threat) be validated through on-site assessments and that the presence of manatees be confirmed through aerial surveys. Direct confirmation of manatee harassment and injury at these sites might be difficult, but the presence of seagrass scarring in shallow, sheltered seagrass beds could serve as a proxy indicator of potential threat. Observations of boater behaviors (e.g., traffic corridors, boat speed) in relation to the available manatee habitat at finer spatial scales is advised, because the spatial precision (and temporal datedness) of the GIS data are inadequate to evaluate the specific location of these resources and current threats within potential MPA regions. To facilitate site-level evaluation and comparison among the 80th percentile regions, we provided region-by-region summaries based on the published and unpublished data, gathered in development of our region-wide models. These should provide a useful starting point for site-level assessment and, in some cases, may provide a historical baseline for manatee resource use. Second, the USFWS might want to consider the effort and costs associated with protection and enforcement at each region. This report does not detail the specific zoning regulations and the spatial configuration necessary to minimize take or the costs associated with education, signage, and enforcement. The spatial data used to assess relative value across the full spatial scope of this study are not of fine-enough spatial resolution, precision, or accuracy to recommend specific zoning regulations within these regions. Options for zoning and enforcement are described in detail in the MPA regulatory documentation (CFR 50: 44 FR 60964, Oct. 22, 1979). However, experts did predict the expected threat-reduction value of diverse MPA watercraft regulations. We also summarized the Miradi result chains, which indicate the specific steps whereby alternative management actions (e.g., education, signage, exclusion of watercraft) are hypothesized to reduce take. These additional products provide information to aid site-level feasibility and cost evaluation, final site selection, and site-level MPA design and monitoring. These activities will require on-site assessments of resources and threats within and proximate to potential MPA regions. Last, current research indicates that manatees in Puerto Rico along the northeast coast may be genetically distinct from those in the south and southwest (Hunter et al. submitted). As a precautionary approach, efforts to protect manatees and reduce take should consider protection of these distinct genetic populations, perhaps by locating at least one MPA in each genetic region.

### 6.2 Proposed MPA Management Actions and Measures of Success

We believe that MPA success can be measured in terms of positive changes in watercraft activity (boater behavior) in regions frequented by manatees. Knowledge of, and respect for, speed or access restrictions could be monitored through public surveys and speed monitoring. This rationale emphasizes human dimensions and not demographic parameters of manatees and is presented below.

If the goal is to reduce take of manatees, management actions must impact anthropogenic activities that negatively impact this species. Experts recognized MPAs as one strategy, among several, that could mitigate anthropogenic threats and thereby reduce take. For example, within the elicitation process, experts identified land-based sources of pollution (e.g. stormwater runoff, nutrient loading) as threats that could not be mitigated by actions taken within an MPA. Presented with their full list of threats, experts distinguished six strategies whereby MPA implementation has the potential to mitigate threats. These are represented within Miradi as results chains and they define the intended objectives of an MPA:

1. Reduce occurrences of motorized watercraft collision with manatees within MPAs by:
    - Reducing presence of watercraft.
    - Reducing and regulating watercraft speeds.
    - Providing education for boaters concerning manatee locations.
2. Reduce the harassment of manatees by:
    - Educating the public about acceptable human behavior around manatees.
3. Provide adequate foraging opportunities (seagrass) by:
    - Reducing illegal/inappropriate anchoring or mooring, which can cause seagrass scarring and turbidity.
    - Reducing recreational activities such as wading or walking on seagrass beds, which can cause seagrass scarring and turbidity.
    - Reducing boating in shallow waters, which can lead to boat groundings and seagrass scarring in seagrass beds.
    - Reducing boating in shallow waters, which can cause turbidity.
    - Regulating dredging activities within MPAs, which can cause seagrass scarring and turbidity which could restrict foraging opportunities.
    - Reducing specific fishing activities, such as seining, that can cause seagrass scarring.
4. Provide safe habitat by reducing opportunities for bycatch and entanglement by:
    - Reducing fishing activities that involve potentially harmful equipment, such as lines and netting activities.
    - Eliminating incompatible fishing activities to reduce threat of abandoned or discarded gear resulting in entanglement.
5. Provide safe habitat by preventing a resurgence of poaching activities by increasing the presence of agency enforcement personnel and conducting monitoring activities within MPAs.

6. Provide safe habitat by reducing opportunities for exposure to environmental contaminants and contaminants associated with bilge water pollution.

Table 8. Fifteen threats to manatees or seagrass could potentially be mitigated through MPA implementation. The threats specific to each regulatory action are identified and the expected impact is ranked as high or medium. Threats not listed in association with a regulatory action were ranked as low or no impact and are not shown.

| MPA Regulation | Impact | Threats Mitigated |
| --- | --- | --- |
| Sanctuary (complete closure to all watercraft) | High | Anchoring, dredging, construction and/or presence of boating facilities, propeller cutting of seagrass, boat groundings, propeller cutting of manatees, motorized watercraft races, shipping channels, noise pollution, boating disturbance, by-catch, abandoned gear and net entanglement, poaching, harassment, and bilge dumping |
| Allowance of non-motorized watercraft | High | Anchoring, dredging, propeller cutting of sea grass, boat groundings, propeller cutting of manatees, motorized watercraft races, collisions, noise pollution, and boat disturbance, by-catch, abandoned gear and net entanglement, oil spills, and bilge dumping |
| Motorized watercrafts permitted seasonally | Medium | Anchoring, propeller cutting of seagrass, boat groundings, propeller cutting of manatees, watercraft collisions, shipping channels, construction and presence of boating facilities, noise pollution, boat disturbance, and by-catch |
| Slow speeds | High | Motorized watercraft races |
| | Medium | Anchoring, noise pollution, boat disturbance, and by-catch |
| Mooring buoys | High | Anchoring |
| Educational materials | Medium | Anchoring, propeller cutting to seagrass, boat groundings, propeller cutting to manatees, watercraft collision with manatees, construction and presence of boating facilities, by-catch, abandoned gear and net entanglement, poaching, and harassment |

Experts identified regulations that could be implemented within MPAs (Table 8). Actions such as the creation of sanctuaries (i.e., restrict all watercraft) or limiting access to allow only non-motorized watercraft were expected to have the highest potential impact on reducing the most threats to manatees and seagrass habitat, but other less stringent restrictions could be beneficial. Combinations of these regulations with other Recovery Plan activities can also be effective in reducing threats. Experts noted the need to quantify baseline conditions and monitor management outcomes to determine the effectiveness of these regulations. As specific type and degree of threats differ between potential MPA sites, conducting baseline surveys of conditions is also essential to determine the specific threats endemic to sites.

A critical point made repeatedly in expert discussions related to how USFWS would potentially measure success of an MPA. An ideal measure of success would be a before/after MPA implementation comparison of manatee harassment and mortality events, showing marked reduction of take, with an associated increase in manatee population size. However, such a direct measure may be infeasible for a number of reasons, at least in the short term. First, there is no effective means beyond self-reporting to directly monitor manatee-watercraft interactions, especially if these are non-lethal. Although take via watercraft injury and mortality has been successfully monitored in Florida, this was accomplished in enclosed canals and waterways (Laist and Shaw 2006). Second, measures of both take and population size are still highly imprecise - too imprecise to observe statistically significant changes without very dramatic changes. Fourth, manatees are long-lived species, such that beneficial changes in population management made today may not be evident in population changes for many years (≥ 20 years: R. Bonde, USGS, personal communication). Finally, as manatees move frequently among regions, it would be very difficult, if not impossible, to attribute a positive change in population size to success of the MPAs (or a decline in population size to their failure). For these reasons, a suggested measure of success for an MPA is *not* take (and associated population increase), but rather the "potential for take" given a set of assumptions about manatees and watercraft threat. Based on the assumption that certain watercraft activities and boater attitudes cause take, the potential for take would be successfully reduced if these activities and attitudes were successfully changed. Before/after and control/impact surveys of watercraft activity and boater attitudes could quantify changes in behavior and attitudes following the establishment of an MPA.

### 6.3 Gaps in Expert Knowledge and Spatial Data

Through the process of defining and spatially modeling the key ecological attributes and threats, experts noted particular knowledge and data gaps that could introduce error or bias into the results. These gaps are important. At minimum, they should inform the field-level site assessments to validate the model predictions. However, these gaps also point to topics of research value to refine the models through testing and updating experts' hypotheses, model assumptions, and spatial data resources. These knowledge gaps might also inform the few unexpected inclusions (e.g., Santa Isabel) and exclusions (e.g., Viequez) in the hypothesis-driven MPA value maps relative to aerial observations.

#### 6.3.1 Expert Knowledge Gaps and the Implications for Interpreting Potential MPA Value

The expert knowledge of manatee habitat selection and threat impacts presented in our workshops highlighted the significant research and monitoring efforts implemented since release of the original Recovery Plan. However, expert discussions also identified knowledge gaps, two of which in particular impact the interpretation and applications of the MPA model results. Experts could offer no knowledge or data to define expected response curves or define thresholds for the key ecological attributes or threats. In the absence of detailed knowledge, experts agreed to the default hypothesis of linear resource values. If a threshold does exist, then such a hypothesis will tend to exaggerate the value of regions with concentrated resources. Similarly, experts could offer no knowledge or data to definitively define the appropriate scale for analysis. Typically, this scale would be set to match a species home range size, daily dispersal distance, or the area of resources required to support one individual. Although the existing telemetry data provide some insight into scale of daily movement among resources, these results are still too highly variable among individuals to formulate concrete estimates. Our selection of a 5 km scale is likely conservative; manatees are known to frequently travel farther than this to access resources, particularly freshwater.

In some cases, key aspects of manatee spatial ecology could not be modeled due to both inadequate expert knowledge and data. Two significant unknowns of potential relevance to positioning MPAs are the importance of travel corridors and nursery habitat. It is unknown if manatee movement patterns preferentially follow certain depth contours or benthic habitat features. Similarly, it is unknown if manatees preferentially select certain regions or depths to give birth or to nurse calves. If certain behaviors are spatially focused, and overlapping with watercraft threat, this would present a high-value potential MPA region.

6.3.2 Spatial Data Limitations and the Implications for Interpreting Potential MPA Value

In some cases, experts offered strong knowledge, but there were no suitable spatial data to translate their knowledge to a spatial model framework. Discussions with experts highlighted potential weaknesses within the spatial data resources that likely introduced error at specific locations around Puerto Rico.

The benthic habitat maps used to depict seagrass are known to be biased by water clarity. Experts noted Bahía de Jobos and Guayanilla as two areas where they were surprised by the low modeled seagrass habitat value, but where they suspected sediment rich waters would obscure the benthic habitats. As most sediments are delivered to the coastal waters via rivers, areas thatscore highest for freshwater input might tend to falsely score lower for seagrass.

Within the freshwater resource value models, experts discussed two important potential biases. On the one hand, when we initially mapped perennial streams using the National Hydrologic Dataset (NHD: Version 2.0, USGS and USEPA 2005), they suspected that these data greatly exaggerated available freshwater. Both the experts and our anonymous reviewers noted several perennially-labeled streams which they knew to be intermittent (e.g., on Culebra and Vieques). We then considered using stream data from the Puerto Rico Gap Analysis Program (PRGAP: Rincon-Diaz et al. 2012). However, the stream classes designated by PRGAP also proved poorly suited to identifying streams suited to manatee use. The final freshwater resource value maps, based on the Atlas Ambiental (López Marrero & Villanueva Colón 2006), generally agreed with experts' knowledge of available freshwater access. The Atlas authors cite USGS as the primary data source (Map 9.1: "Agua superficial: ríos y cuencas principales") but provide no documentation of the specific dataset or the rules used to distinguish principal streams from minor or intermittent streams. Ground-truthing the mapped surface freshwater resources, therefore, will be critical to ensure that the mapped water resources within a proposed MPA region are, in fact, perennial resources.

The role of groundwater remains a potentially significant but undefined freshwater resource for manatees. Groundwater discharge has not been spatially modeled for the entire scope and was unable to be incorporated. Therefore, the resulting value map for freshwater access may underestimate the value of regions where manatees are known to benefit from groundwater discharge to coastal waters, such as Bahía de Jobos. Groundwater studies in Bahía de Jobos (Kuniansky and Rodríguez 2010) and southwest Puerto Rico (Quiñones and Torres 2003) indicate that these resources could be substantial but do not indicate if the freshwater would be available as a point source resource for manatee use. Data regarding extent of groundwater discharge to coastal water in other regions of Puerto Rico were unavailable.

The manatee experts did not disagree with the findings from the shelter model, but the model developers warned of one potential bias that could exaggerate the relative shelter value of southwest exposed coastlines (e.g., vicinity of Santa Isabel). The shelter model developed in WEMO 4.0 depends upon wind station data to define prevailing wind speed and direction, and while the eastern half of scope area is well represented by five stations, the western half only has two stations. Furthermore, the southernmost station, which determined the wind field parameters for the southern coast in the shelter model, was a buoy located more than 12 km offshore from Ponce. It is possible that the windfield from this buoy did not adequately represent the windfield closer to shore, where the sheltered waters would be found. There were no other weather stations that had data of adequate quality for the shelter model found in a more representative location along that shoreline. Additional windfield measurements would improve the sheltered areas model, with the most important locations for new data being near the SW point, around Boquerón, El Combate, Pole Ojea, or La Parguera. The prevailing wind changes from west to east in that region, and there are no indications of the transition in the windfield measurements that we currently have. Additional windfield measurements along the southern coast of the island, to replace the offshore buoy data, would also be helpful. The output of the wave energy model is an average of the general conditions found throughout the year, and thus does not represent specific conditions found at any particular time. A predicted sheltered area could be informally validated, however, by measuring average wave height under a variety of ambient wind conditions to confirm that they remain below 0.3 m, which was the largest average wave height predicted by the model in the sheltered areas.

The watercraft threat model required many simplifying assumptions and represents the most uncertain data layer within the model. The various watercraft activities documented, although represented spatially as point data, likely represent highly variable concentrations of watercraft and levels of impact. However, watercraft activity is a variable that could feasibly be monitored in a manner to provide much more useful information. If the PRDENR methods used to research watercraft concentration and impacts to reef and seagrass were modified to distinguish motorized from non-motorized watercraft and then repeated at each of the potential MPA regions (or even scope-wide), this could provide valuable validation of these data. Such a survey would also provide a baseline prior to the implementation of any MPA management strategies.

## 7. CONCLUSION

Our model to identify and compare potential MPA sites represents experts' hypotheses regarding manatee requirements and threats, based on their synthesis of available empirical data and their professional experience. This hypothesis-driven regional valuation approach clearly articulates assumptions about manatee ecology and anthropogenic threats. Simply identifying regions with the highest number of manatees, the best habitat, or the highest documented mortality would not have necessarily identified regions with the greatest potential to reduce take. Even more important, however, it would not lead to greater knowledge of the processes that drive manatee distribution patterns. Such knowledge will be essential if manatee habitat resources, and thus manatee distribution patterns, change due to climate change or other impacts (e.g., change in water resource availability, location and density of seagrass beds, etc.).

The potential MPA regions identified in this report specifically addressed the legal definition of an MPA's purpose: to prevent or reduce take of manatee (CFR 50: 44 FR 60964, Oct. 22, 1979). The original Recovery Plan recommended protection of suitable habitat and management of watercraft activities as a primary means to protect manatees from direct anthropogenic threat and harassment. General MPA implementation strategies (e.g., watercraft access and speed regulations, signage, and boater education) were affirmed by this project's expert participants, with the caveat that the implementation of one or more MPAs could be one of several coordinated recovery strategies that would be considered in the revised Recovery Plan.

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### 9.2 Personal Communications

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Jan P. Zegarra, U.S. Fish and Wildlife Service (USFWS), Caribbean Field Office, Boquerón, PR

### 9.3 Unpublished Data

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U.S. Fish and Wildlife Service (USFWS) Aerial survey data 1984-2002. Received from: Jan P. Zegarra, Caribbean Field Office, Boquerón, PR

## 10. DIGITAL APPENDICES

Appendix 1: Materials from Expert Workshops and Surveys

Appendix 2: Draft Spatial Models with Associated Expert Discussions

Appendix 3: List of Documents and Data Files Delivered with the Report