APPENDIX 2: DRAFT SPATIAL MODELS WITH ASSOCIATED EXPERT DISCUSSIONS

As described in the report methods, we matched the information gathered in the first workshop (manatee key ecological attributes and threats) with available spatial data resources. These spatial data were used to model the hypothesized relationships between the attributes and threats and the potential MPA value for all waters within the project scope. At the second workshop, we asked experts to: (1) review the key ecological attribute and threat hypotheses, (2) indicate whether the data selected to spatially model the hypotheses represented the “best available data” at the scope-wide scale, and (3) assess the plausibility and relevance of the resulting value maps. In most cases, significant changes were recommended. While the report text presents the final model methods and results, this appendix provides documentation of earlier drafts and the associated discussions and decisions.

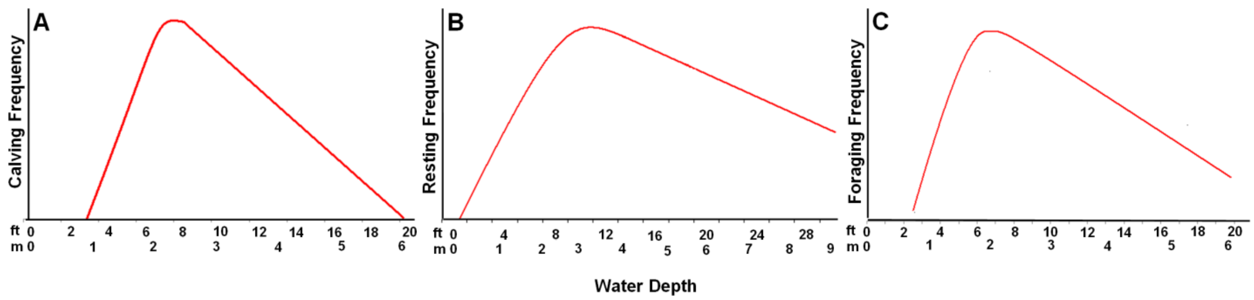
In each section below, we provide the questions and materials presented at the second workshop for expert review (HYPOTHESES, DATA RESOURCES, and DATA INTERPRETATION & APPLICATION sections) organized under key ecological attribute and threat headings. Under each heading, we then summarize the comments, concerns, and recommendations we received as feedback both at the second workshop and through subsequent revisions (DISCUSSION & REVISIONS section). None of the materials presented in this appendix are final products. The purpose of this appendix is to provide transparency regarding the evolution of the expert-based models presented in the final MPA report. Minor modifications have been made to the following text and figures to clarify the instructions and comments delivered verbally at the workshop. Throughout, bolded text indicates questions posed to experts regarding the associated set of hypotheses, data resources, or map figures.

Key Ecological Attribute: WATER DEPTH

HYPOTHESES

Do these statements and figures accurately capture hypothesized relationships between manatees and water depths in Puerto Rico?

- The optimal depth for calving is between 6-10 ft with 3 ft being too shallow and anything greater than 20 ft being too deep (Graph A)
- The optimal resting depth for manatees is approximately 14 ft (Graph B)
- Manatees feed in water depths greater than 3ft and less than 20 ft. Depths less than 3 feet are considered too shallow and seagrass rarely growing at depths greater than 30-40 feet. According to Lefebvre et al. (2000) the mean depth for feeding manatees was 2.03m (6.6 feet) with a range of 1-5m (3.2 feet – 16.4 feet). (Graph C)



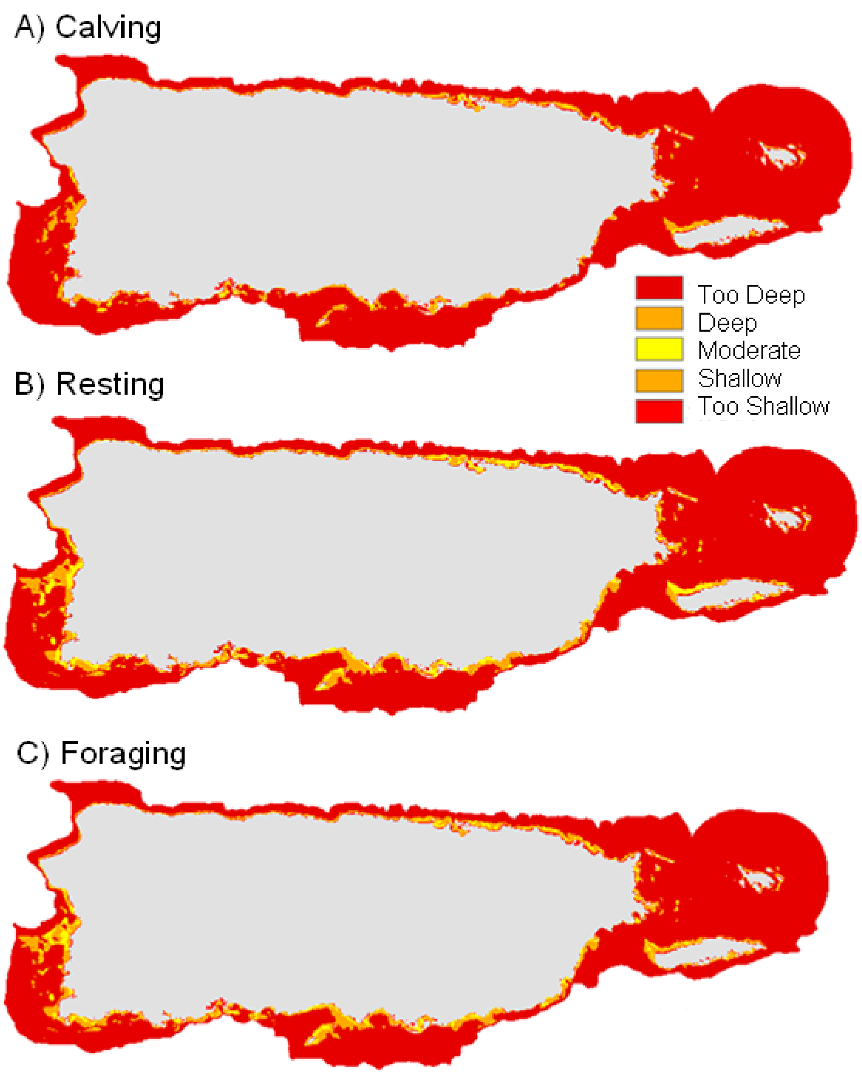
DATA RESOURCES

Are these resources the best available data to spatially represent bathymetry data for manatee activities?

We downloaded the Puerto Rico section of NOAA's Coastal Relief Model (CRM) of the U.S. coastal zone (http://www.ngdc.noaa.gov/mgg/coastal/crm.html). The CRM database contains grids, or digital elevation models (DEMs), of the entire coastal zone of the conterminous U.S., as well as Hawaii and Puerto Rico (http://www.ngdc.noaa.gov/mgg/coastal/crm.html) at an 80 m horizontal resolution (raster grid cell size) and 1 m vertical resolution. The regional downloads of these data do not have associated, published metadata (B. Costa, pers. comm.); the vertical and horizontal accuracy is undocumented. For the purposes of this model, we rescaled the data to 30 m grid cell size to match our other data resources. This scale reduction increases the potential error, as the average reported depth within an 80 m is attributed to multiple pixels (up to 4 neighboring pixels) that could in fact have slightly different average depths. However, given the fine scale (1 m) vertical depth increments, the gradual nature of depth changes on most shallow coastal waters, and our assessment method which valued pixels based sums or averages within 5 km radius regions, we determined the introduced error was unlikely to significantly impact the final MPA value assessments. Model representations are based on the identification of depth increments for the specific manatee activities of calving, resting, and feeding.

DATA INTERPRETATION & APPLICATION

Do these maps represent a reasonable hypothesis of the spatial distribution of areas of appropriate depth where manatees calve (Map A), rest (Map B), and forage (Map C)?



DISCUSSION & REVISIONS

The second workshop featured presentation of preliminary results of telemetry data of several manatees in Puerto Rico. These data provided support for arguments that manatees strongly select shallow water (1-3 m depth) for the majority of their non-travel activities. The discussion among experts focused on whether it was more appropriate to generate separate value maps for all three activities (calving, resting, and foraging) or to treat depth as a single key ecological attribute (one value map). Experts debated which activities could be clearly observed and attributed to a particular location and associated depth. They concluded that calving is not directly observed, so they could not offer any knowledge base to hypothesize a suitable depth range. However, resting and foraging are both behaviors that they regularly observe and associate with specific locations using aerial and telemetry survey methods.

The discussion then focused on whether depth is itself the key ecological attribute by which manatees select habitat for resting and foraging. These were felt to be separate behaviors that should be represented by separate value models; a single manatee might travel between one area to rest and another area to forage and these sites could present different depth profiles. Several experts hypothesized that it was not depth, but rather shelter, that manatees seek, especially when resting. The telemetry data provided preliminary, untested support for such a hypothesis. Shelter was also suspected to be critical for manatees with calves, though there were no data to support or reject a hypothesis that sheltered waters promoted higher calf survival.

Experts concluded that they did not want the models to treat “Depth” as a key ecological attribute and instead requested that we:

(1) Change the way that depth is applied as a modifier to the key ecological attribute “Seagrass”
(2) Define a new key ecological attribute “Shelter”

Changes to the seagrass model are discussed further in the seagrass section of this appendix. Defining “shelter” as a key ecological attribute required scope-wide spatial data of sheltered waters. Such data did not exist, but could be generated from available wind, bathymetry, and manatee telemetry data.

Key Ecological Attribute: SHALLOW SEAGRASS

HYPOTHESES

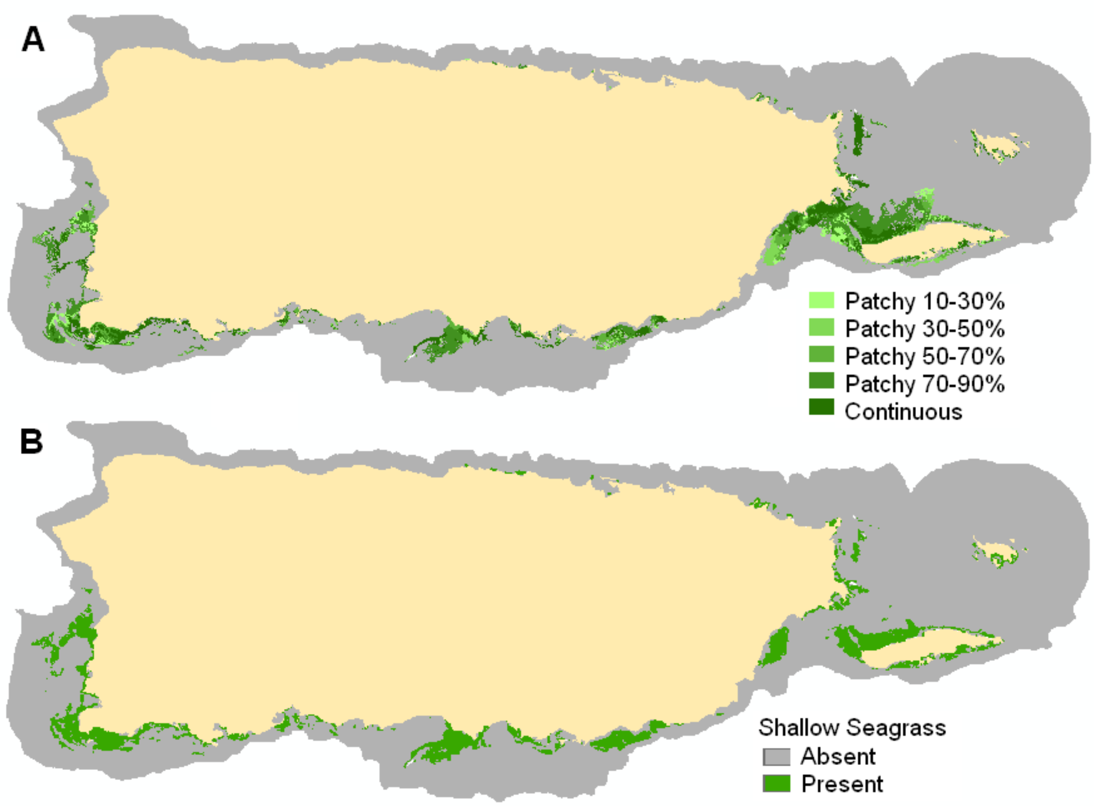
Do these statements accurately capture hypothesized relationships between manatees and seagrass forage resources in Puerto Rico?

- Manatees consume a variety of seagrass species, but in unknown proportion and with unknown selectivity relative to availability.
- Manatees prefer to feed in shallow seagrass (see Bathymetry section above with foraging data profile).
- A single manatee will graze seagrass in a seagrass patch of any size, but a large area of seagrass could sustainably support more manatees than a small area of seagrass.

DATA RESOURCES

Are these resources the best available data to spatially represent seagrass as foraging resources for manatee?

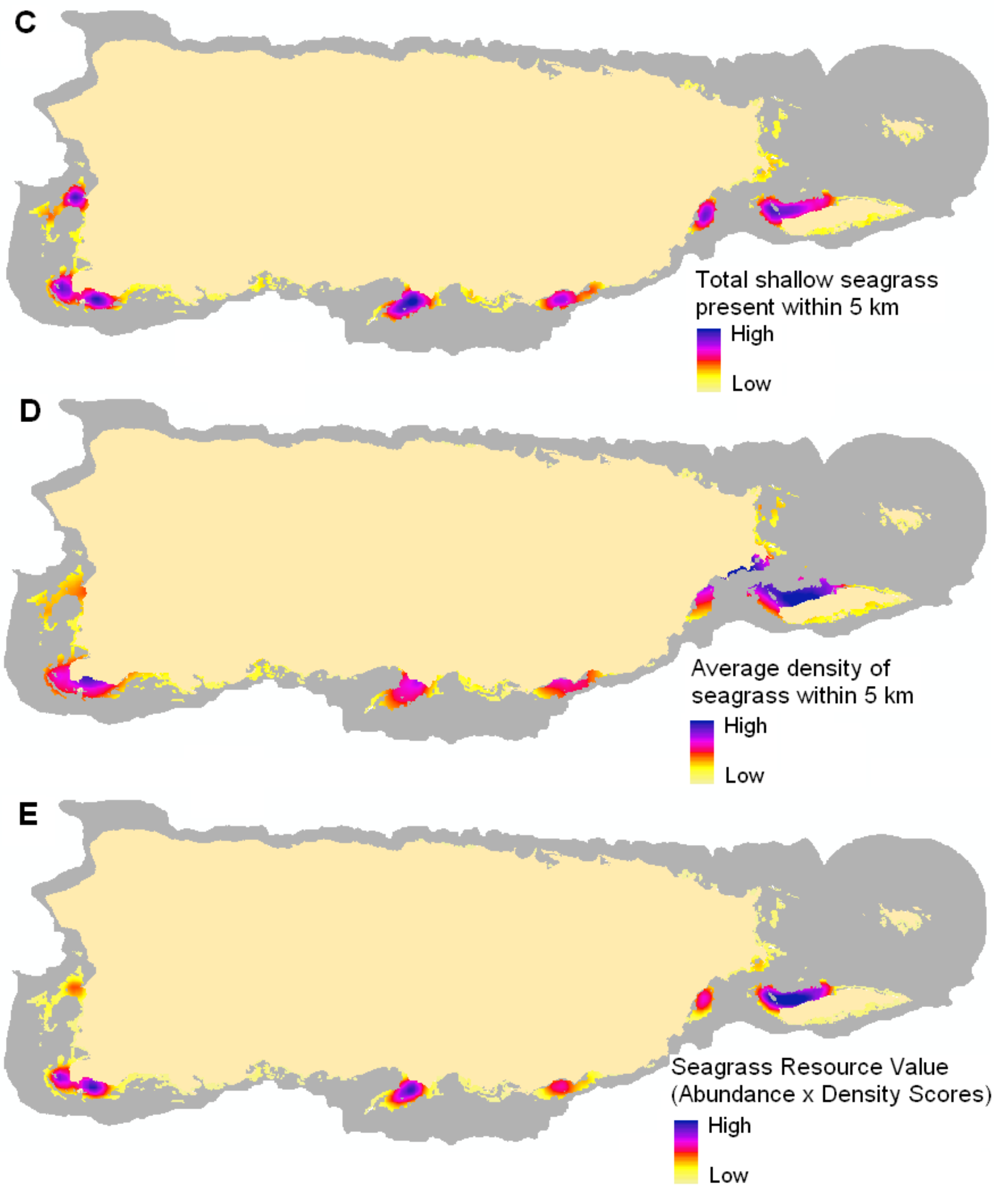
NOAA's Benthic Habitats of Puerto Rico data (http://ccma.nos.noaa.gov/ecosystems/coralreef/usvi_pr_mapping.aspx) classify benthic features into twenty-six habitat types and nine geomorphological zones ranging from sand to coral and shoreline to shelf edge respectively. These include seagrass habitat (Map A) attributed as continuous or patchy, and if patchy, attributed with a percent cover classification (10-30%, 30-50%, 50-70%, or 70-90%). The metadata documentation (http://ccma.nos.noaa.gov/products/biogeography/benthic/data/pr_shp/metadata/p_rico.html) reports that the maps have a spatial accuracy of 1 to 9 m and a thematic accuracy of 93.6% overall. Produced in 2001, based on 1999 aerial imagery, the degree to which habitats have changed since 1999 is unknown. The majority, but not all seagrass areas are shallow enough to serve as manatee forage habitat (Map B).



To evaluate seagrass habitat, the Benthic Habitat data were converted to 30 m raster grid format and all shallow water (<13 m) seagrass pixels (Map B) were extracted to two new files. One file valued pixels as 0 or 1, for absence or presence of seagrass. The second file valued the pixels based on the median of their percent cover classification, 0 (absent), 20 (patchy with 10-30% cover), 40 (patchy with 30-50% cover), 60 (patchy with 50-70% cover), 80 (patchy with 70-90% cover), and 100 (continuous). At the first workshop, experts indicated that simple presence of seagrass was adequate to provide manatee habitat (i.e., that manatees were not selective based on extent or patchiness of seagrass beds). However, nearly the entire coastline has at least one seagrass pixel present within 5 km, and thus would receive equal value under a presence/absence valuation system. Therefore we ran three models to value of a seagrass forage habitat within 5 km of each pixel: the total extent (total area) of seagrass present (Map C), the average patchiness of the available seagrass (Map D), and the multiplicative combination of these two values (Map E). The first model represents relative quantity, the second relative quality, and the last a relative score that balances quality and quantity.

<u>DATA INTERPRETATION & APPLICATION</u>

Do these maps (C, D, and E) represent a reasonable hypothesis of the spatial distribution of areas of with higher availability and quality of seagrass as forage habitat?



DISCUSSION & REVISIONS

An initial correction to these maps was the need to apply the value beyond the shallow regions to match all other data layers. All map layers are meant to represent access to resources. Thus, for the MPA valuation, a pixel valued 0 for seagrass presence could still have a seagrass habitat value if neighboring pixels within the 5 km radius contain seagrass.

Reviewing the data within the value maps (C, D, and E), experts discussed concerns about possible error in the seagrass data. First, seagrass beds are dynamic habitats. The snapshot of mapped habitats based on 1999 imagery may not reflect current conditions, as individual beds may have moved, expanded, or shrunk since data were generated. Second, several experts identified specific sites where the mapped data may under-represent the quantity of available seagrass. These included Bahía de Jobos and Guayanilla, two areas where manatees are known to regularly forage. The presence of murky waters in these bays was identified as a possible source of mapping error, as murky waters obscure bethic habitats in aerial imagery. Experts noted that much of southwest Puerto Rico is currently being remapped by NOAA (http://ccma.nos.noaa.gov/ecosystems/coralreef/benthic_swpr.aspx) and these updated data might provide insight into both benthic habitat change and map error. However, in the interim, experts agreed that the data presented were the best (and only) scope-wide data resource to evaluate relative value of seagrass forage habitat.

Experts debated the value of the percentage cover information and ultimately requested that it be deleted from the analysis. They did not support the hypothesis that manatees preferentially forage in continuous rather than patchy seagrass beds.

Generally, experts maintained that seagrass habitat was likely not a limiting resource for current manatee populations at either scope-wide scales or within the "hotspot" bays (i.e., sites with frequent manatee observations). For the purposes of assigning a relative forage value to pixels within the study scope, experts debated whether a linear or parabolic function represented a more appropriate hypothesis. Experts in the first workshop had defined a parabolic function with a maximum at 2-3 m depth. Telemetry data presented at the second workshop confirmed this apparent preference for shallow water, but indicated manatees would also frequently forage in water as shallow as 1 m (the minimum depth in our bathymetry maps). The final decision was to assign each seagrass presence pixel a value based on depth: seagrass pixel values decreased linearly from a value of one at 1 m depth to a value of zero at 13 m and deeper. This represented the simplest hypothesis in the absence of further information to define parameters for a curvilinear relationship.

Key Ecological Attribute: FRESHWATER

HYPOTHESES

Do these statements accurately capture hypothesized relationship between freshwater access and manatee habitat requirements in Puerto Rico?

- Manatees require regular access to freshwater

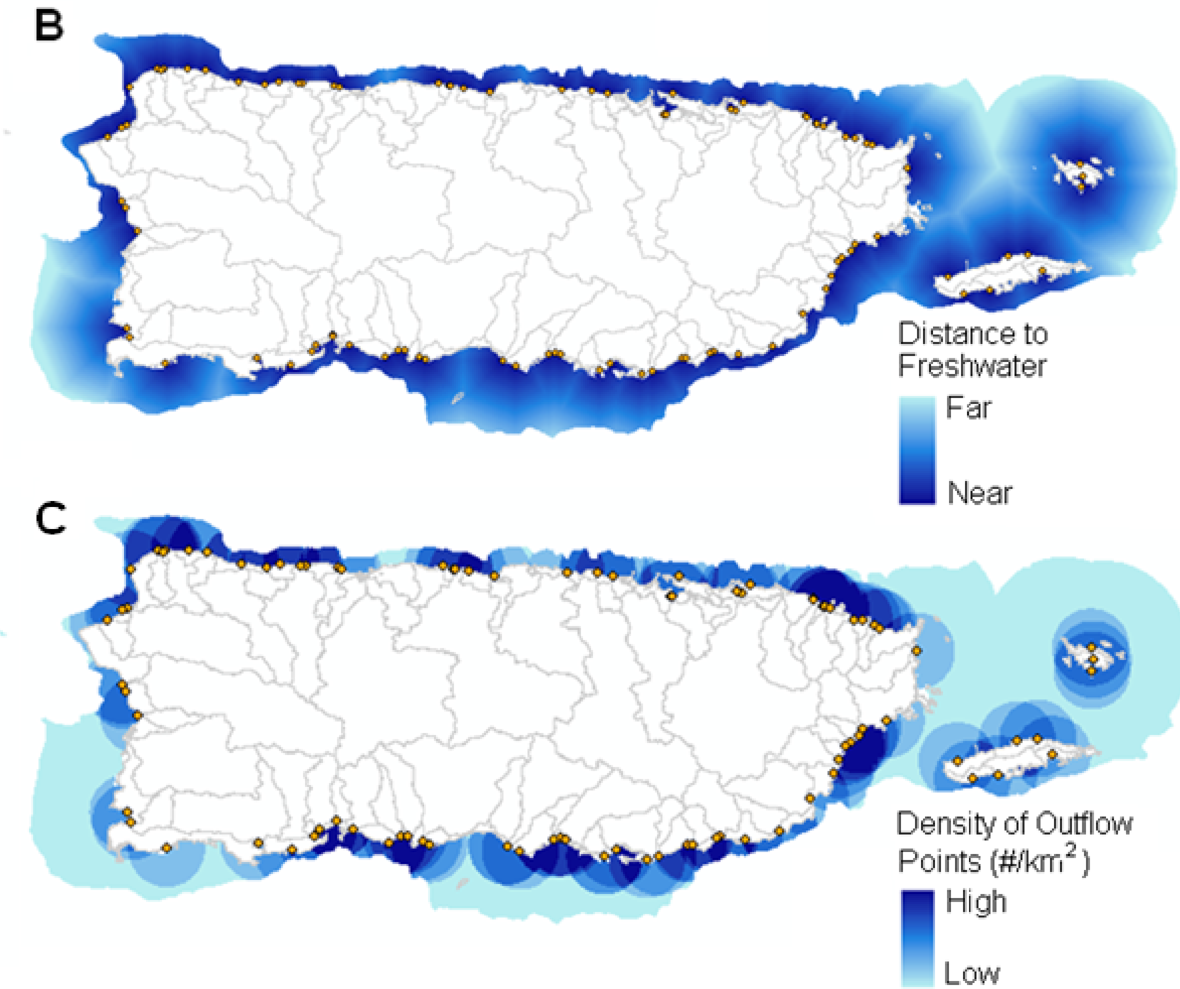
- Manatees will travel up to 20 miles (32 km) from freshwater resources, but generally remain within 5 miles (8 km) of freshwater resources
- Manatees are not known to avoid polluted or industrial waters or to preferentially select clean or natural water resources.

DATA RESOURCES

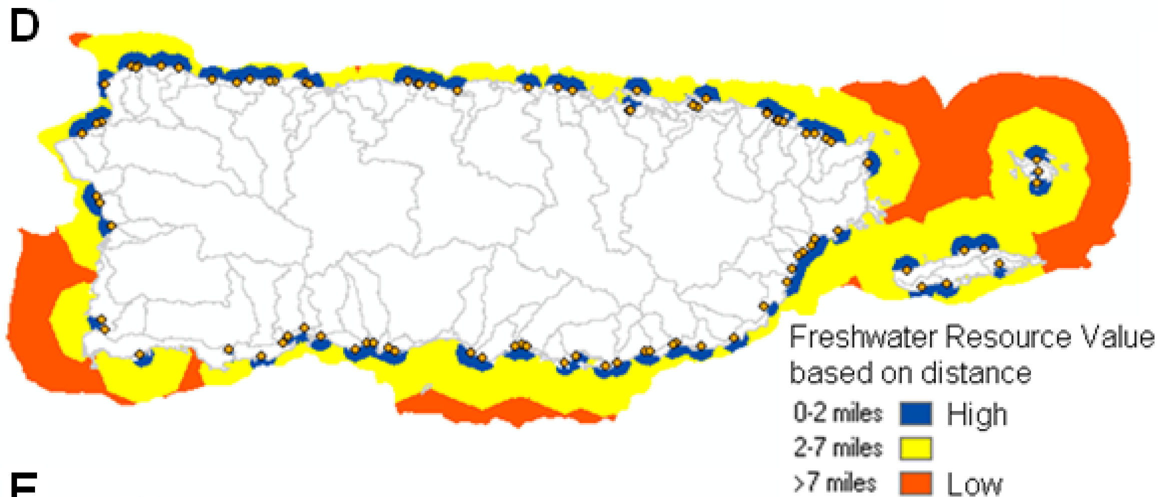
Are these resources (Map A) the best available data to spatially represent freshwater access points?

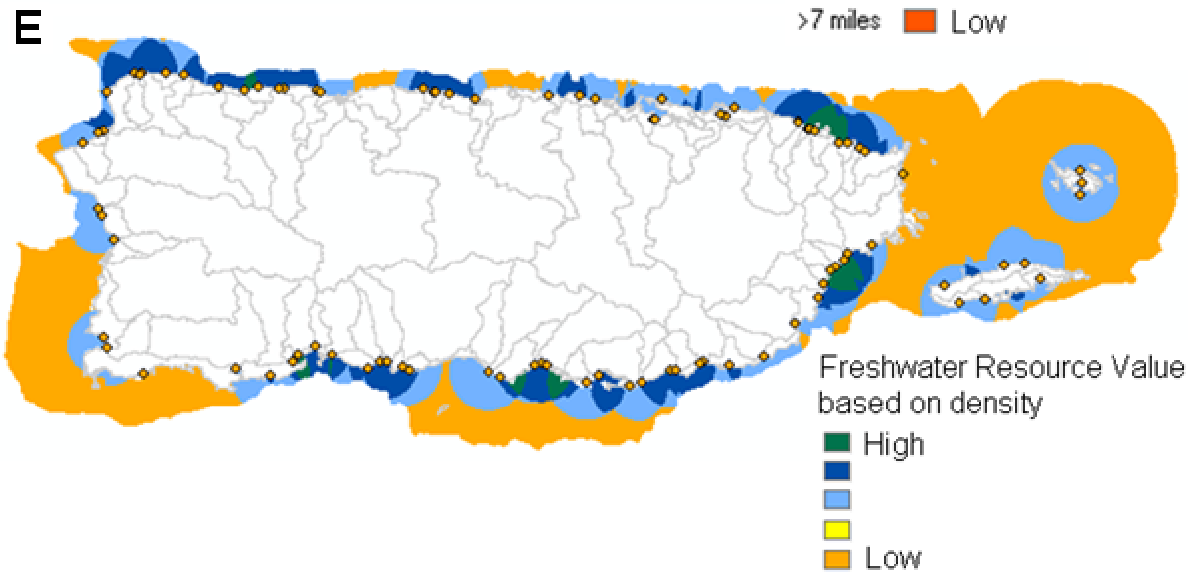
We downloaded data from the Summit to Sea Characterization of Coastal Watersheds: Puerto Rico and U.S. Virgin Islands website: (http://ccma.nos.noaa.gov/ecosystems/coralreef/summit_sea/summit_sea2.aspx). The Summit to Sea project (StS) models land-based sources of sedimentation and pollution threat to coral reefs, but includes a drainage basin map as one of their ancillary data layers. This drainage map includes 132 stream outflow points within our scope area. To account for watersheds that might be too small to deliver consistent freshwater flow, we removed points representing outflow from watersheds less than 2 km^2 in area. This left 96 points for our analysis.

Access to freshwater could be considered from at least two perspectives: distance to nearest freshwater source (Map B) or the density of freshwater sources available within a given area (Map C). The distance measurement provides a proxy for how far a manatee might travel, while density might provide a proxy for resource security. If stream outlets have variable flow rates, variable water quality, and variable levels of boating disturbance, then regions offering a higher density of freshwater resources offer more alternatives to manatees seeking high quality, undisturbed resource access.


B
Distance to Freshwater
Far
Near
C
Density of Outflow Points (#/km²)
High
Low

Does either map (D or E) represent a reasonable hypothesis of spatial distribution of manatee habitat value in relation to fresh water access?





DISCUSSION & REVISIONS

Freshwater discussions at the second workshop focused on the necessity of including additional freshwater resources (e.g. industrial outflows), the accuracy of the Summit to Sea outflow point location data, and whether "presence/absence" of freshwater provided a better value measure for this key ecological attribute. The Atlas Ambiental de Puerto Rico (López Marrero & Villaneuva Colón 2006) includes maps of wastewater treatment plants, hydroelectric, and petroleum processing outflow points. As manatees are known to utilize some of these industrial water resources, experts requested that these data points be added to the models. The Autoridad de Acueductos y Alcantarillados provided data for wastewater treatment plants. We added the hydroelectric outfall location in Bahía de Jobos by locating this feature on Google Earth.

Experts questioned the accuracy of the Summit to Sea outflow points (Map A), noting both errors of commission and omission of perennial freshwater resources. They requested that we instead use the USGS National Hydrologic Dataset (http://nhd.usgs.gov/index.html). We downloaded these data and then extracted only those streams classified as perennial streams. While manatees may use freshwater from intermittent streams when available, experts requested that the relative freshwater resource value of a region only reflect year-round water resources. When experts reviewed the freshwater resource maps (Figure 7, in report main text), they expressed surprise at the number of streams classified as perennial, which they would have expected to be classified as intermittent. In particular, they stated that Culebra did not have any perennial streams, yet the map showed several perennial outflow points. They debated whether it might be better to use discharge data to distinguish between streams, but two factors led to the decision to keep perennial streams as the model input. First, there was no knowledge to support a consensus on what discharge levels would be appropriate to distinguish between streams to include versus exclude from the model. Second, even if the perennial classification is over-representing water resources, any error in their method has been consistently applied over the full extent of the scope, thus should not generate regional biases in the relative value estimates. However, they noted that it would be critical to ground-truth these data prior to establishing an MPA.

Experts initially argued that freshwater should be valued based on simple presence/absence of at least one freshwater source within the 5 km radius analysis region. However, as the majority of Puerto Rican coastal waters are within 5 km of a freshwater source, all coastal waters ranked equally under this valuation method. Experts therefore suggested we use the number of freshwater resources within the 5 km window as the valuation method.

Ultimately, this map based on National Hydrologic Data was also determined to overestimate the number of perennial freshwater resources available to manatee. Experts determined that the major rivers as mapped in the Atlas Ambiental de Puerto Rico provided the best fit with their knowledge of freshwater resources available to manatees. The final version of the model used these data as described in the report.

Threat: SEDIMENTATION

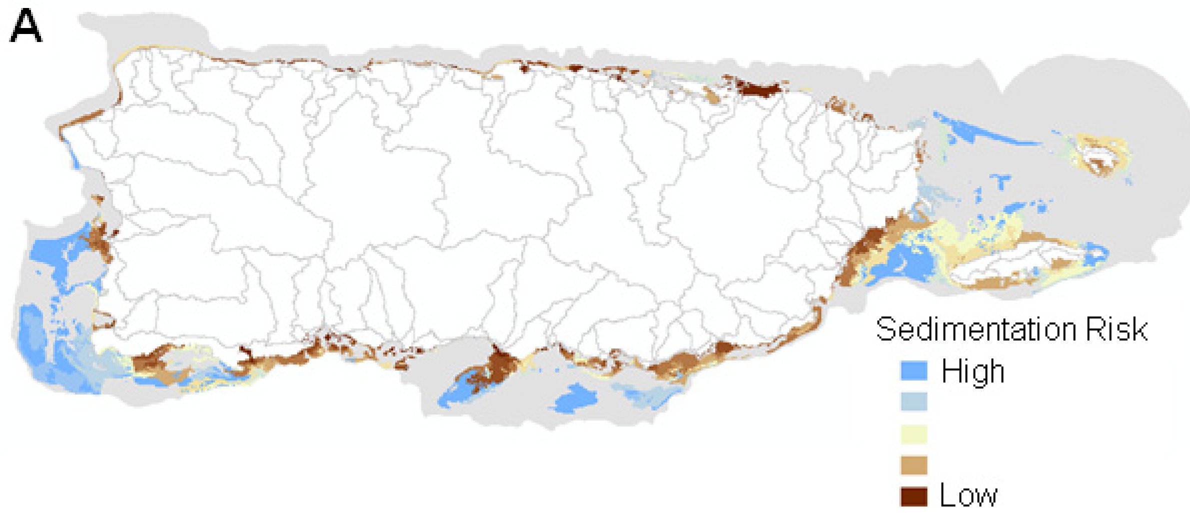
HYPOTHESES:

Do these statements accurately capture hypothesized relationship between manatees and sedimentation threats?

- Increase Sedimentation -> Decrease Seagrass -> Decrease Quality of Manatee Habitat
- Increase Sedimentation -> Decrease Visibility -> Increase Manatee-Watercraft Collisions

DATA RESOURCES:

Are these resources (Map A) the best available data to spatially represent sedimentation threats?

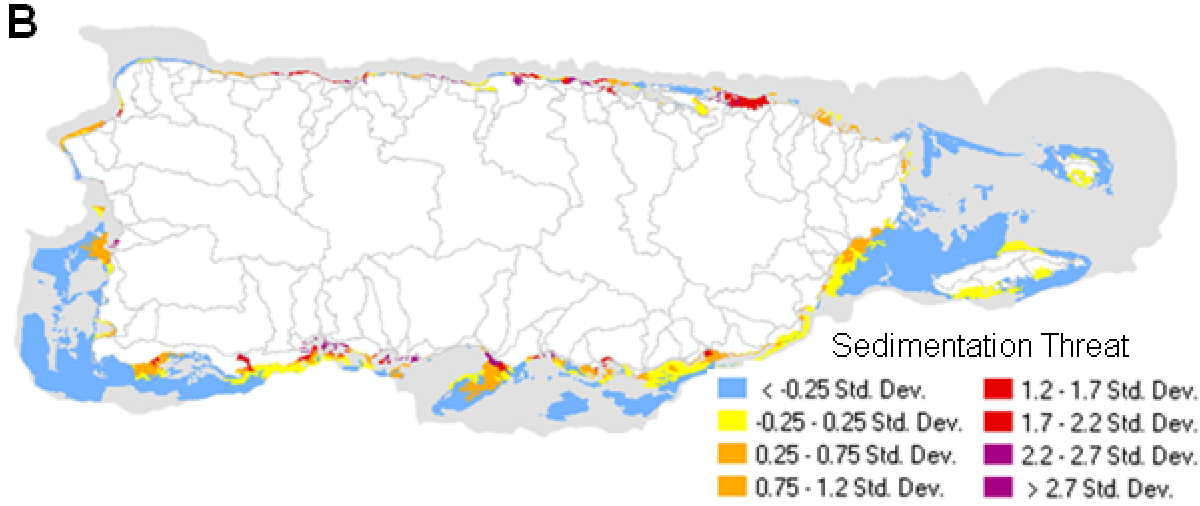


Relative Sedimentation Threat

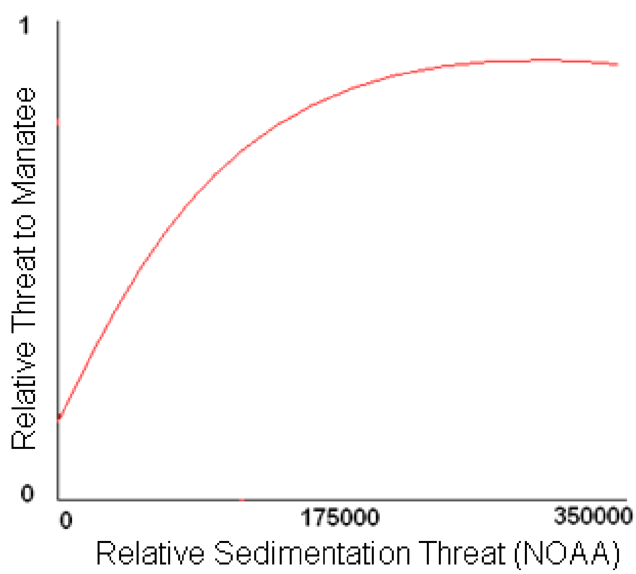
NOAA calculated potential threat of sediment delivery and land-based sources of pollution to benthic habitats in Puerto Rico and US Virgin Islands as part of the Summit to Sea Characterization of Coastal Watersheds (http://ccma.nos.noaa.gov/ecosystems/coralreef/summit_sea2.html). Full metadata are available on their website. They modeled the mean relative erosion potential by watershed and sediment delivery potential at outflow using spatial data on slope, drainage, erosivity, and precipitation. The model calculations were based on RUSLE (USDA 1989) modified to account for unique Caribbean soils and landscapes. The point density tool was used to create the continuous benthic threat layer, using the sediment delivery at the outflow point as input, and a kernel radius of 5 km for Puerto Rico. Relative Sedimentation Threat, shown for all NOAA mapped benthic habitats, is a log-scaled unitless index of the expected level of sedimentation outflowing from watersheds.

DATA INTERPRETATION & APPLICATION

Does this threat map (B) represent a reasonable hypothesis of the spatial distribution of relative threats to manatee due to sedimentation?



Relative Sedimentation Threat values ranged from 0 to 327058 (N = 4989 30m pixels). Mean = 16124; SD = 34606. This is a relative scale: the relative values have not been related to field measures of sedimentation. In the first workshop, experts were unable to hypothesize a relationship between this relative scale and manatee. No data or knowledge existed to identify where along this scale sediment levels begin to negatively impact manatees, either through reduction of visibility or degradation of seagrass beds. Therefore, as a baseline uninformed hypothesis, the threat levels are evaluated in standard deviation units. The center (mean) of the distribution is identified as a Moderate threat level, and threat levels increase or decrease from the mean in standard deviation defined bins.



Ideally this figure would include two response curves – one for the direct threat to manatees through reduced visibility and increased collisions and one for the indirect threat to seagrass habitat. However, in the absence of data to quantify the sedimentation scale and the absence of data to define the correlation between sedimentation and the manatee threats, we simplified the models to present one hypothesized response curve.

DISCUSSION & REVISIONS

Experts debated the value of the sediment data and ultimately requested that this variable be removed from the MPA model. This decision was based on two primary factors. First, experts reached a consensus perspective that there were no data or knowledge resources available to link sedimentation risk to manatee threat. Also, while high sediment loads could definitely impact seagrass beds where manatees forage, they argued there was no evidence that sedimentation directly threatened manatees (e.g. via boat visibility). Second, and more critically for model design, sedimentation is a land-based threat which cannot be mitigated through management actions within an MPA. Therefore, it did not meet our criteria for defining MPA threats. Experts therefore agreed that while sedimentation should be considered in later MPA site assessments in the field, it was a threat that would be addressed through other management actions through the broader recover plan process, rather than through the establishment of an MPA.

Threat: MOTORIZED WATERCRAFT

HYPOTHESES

Do these statements accurately capture hypothesized relationships between watercraft and manatee?

- Motorized watercraft present one of the greatest threats to manatee and manatee habitat in Puerto Rico.
- Increase density of motorized watercraft -> Increased threat of manatee collisions
- Increase density of motorized watercraft -> Increased threat of manatee disturbance & harassment
- Motorized watercraft indirectly and negatively impact manatee through damage to shallow water seagrass habitat by boat props and anchors.
- Threat from motorized watercraft is non-seasonal (i.e. roughly equal across all seasons).

DATA RESOURCES

Are these resources (Maps A and B) the best available data to spatially represent watercraft activity? Is the information provided by the boating infrastructure redundant to the results provided by the boating impacts study?

Watercraft Infrastructure
Boating infrastructure includes marinas, docks, shipping channels, mooring buoys. We obtained data for some, but not all boating infrastructure. In some cases, data gaps are geographic in nature (e.g. boat ramp data not available for Culebra and Vieques), others are agency gaps (e.g. mooring buoy data only available for state and federal conservation areas), and yet others are due to uneven data reporting (e.g. self-reporting of marina data results in unknown data quality). We gathered data on boating infrastructure to serve as a proxy for boating activity. We later received data documenting watercraft concentrations and benthic habitat damage, which may provide a more direct measure of watercraft threats, negating the need to include boating infrastructure information.

Mooring Buoys
The DRNA provided locations of 270 buoys. These data represent all recreational buoys established as of March 31, 2010 in Puerto Rico. Their report describes the data thus:

> "Recreational mooring buoys are installed where there are high concentrations of boating activities and sensitive marine habitats that could be damaged by boat anchoring. The data included the latitude and longitude coordinates for recreational buoys. We digitized the location of individual buoys using GIS software to produce final set of 270 point records collected from the 2008-2010 annual progress report which evaluates recreational boating anchor damage on coral reefs and seagrass beds. Each point denotes one mooring buoy."

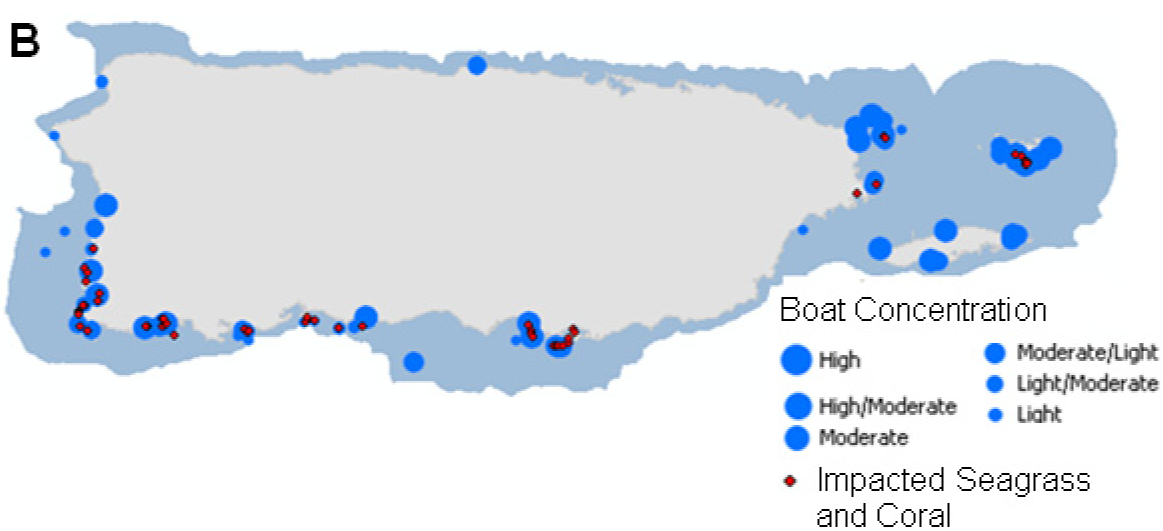
Experts had not reached consensus regarding the impact of mooring buoys on manatee populations. While mooring buoys provide an alternative to anchoring in fragile habitats, they also may concentrate boating activity. Poorly designed mooring buoys can damage seagrass and coral habitat. We therefore require clarification of whether, and if so how, experts would like to see these data incorporated in to the MPA design process.

Boat Ramps
The DRNA also provided location data for boat ramp facilities along the Puerto Rican coast (excluding Culebra, Vieques, and Desecheo). These data came from a 2005 inventory of all existing and potential boat ramp sites in support of developing a comprehensive ramp development planning process (Dickson et al 2005). The project documented ramp dimensions, surrounding environmental conditions, wave action, and parking availability within a georeferenced database.

Marinas
Workshop participants were unable to provide geographic data for marinas. Therefore, we accessed the Travel and Sports website for Puerto Rico (http://travelandsports.com/ma.htm accessed October 2010) to identify marina facilities. This webpage listed 20 marinas in Puerto Rico. Using GoogleEarth software, we visually confirmed the address or location description of 19 of the listed marinas. We digitized the coordinates of these 19 marinas in GoogleEarth and then converted these data to a point shapefile for use in ArcGIS. This process likely underestimates the true number of marinas.

Shipping Channels
We did not receive digital data of commercial shipping channels.

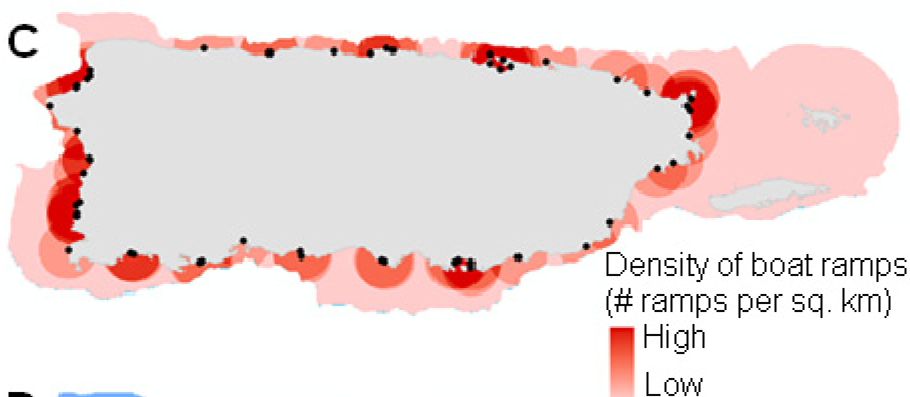
<u>Watercraft Density</u>
The DRNA provided digital data from their 2008-2010 report on recreation boating activities and their impacts on benthic habitat resources. This report documented damage to seagrass beds through assessment of aerial imagery (2008-2010). However, the study was not conducted scope-wide, but rather focused on pre-selected areas of concern. Large sections of coasts show no boats, which in fact were not surveyed within this study.

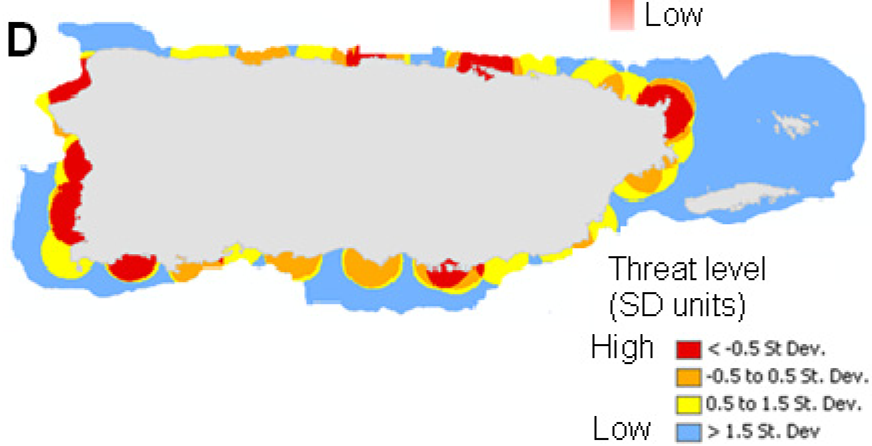


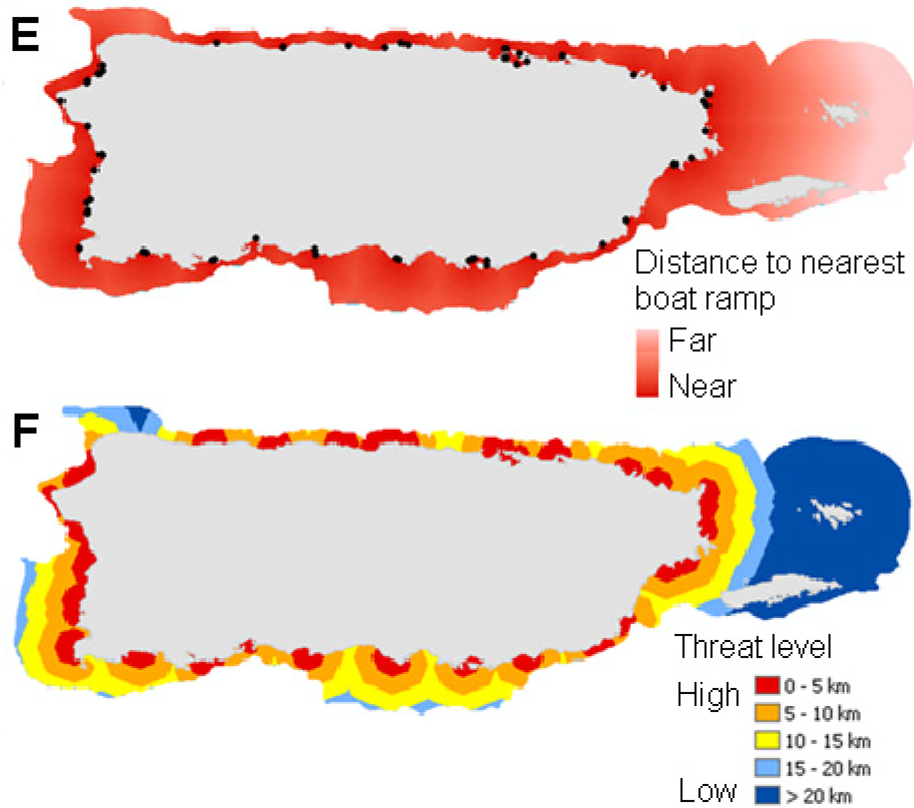
DATA INTERPRETATION & APPLICATION:

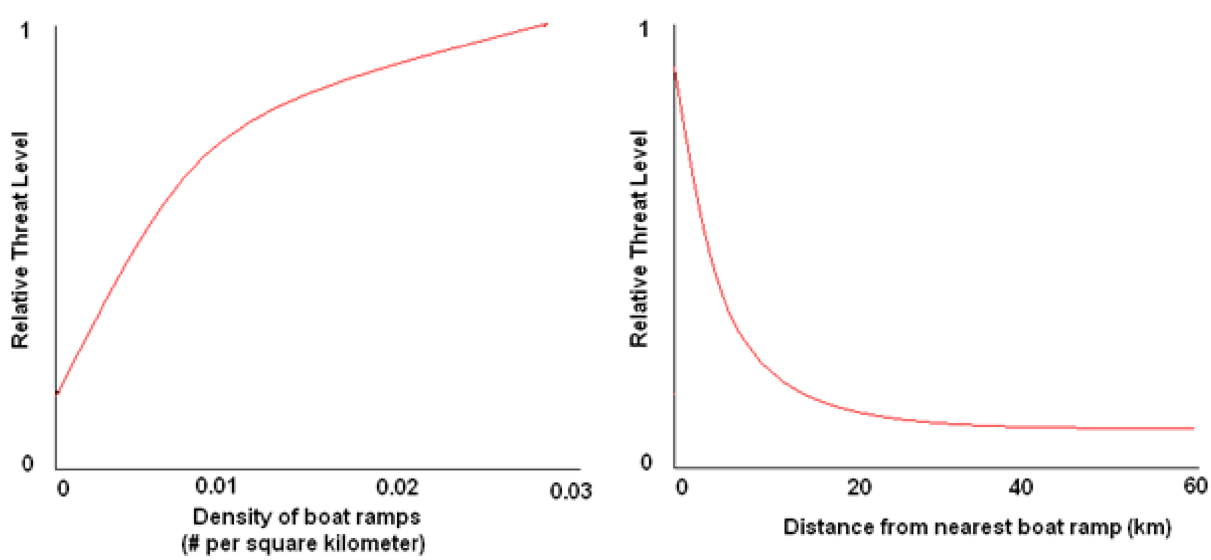
Do the statements and graphs accurately interpret watercraft threat hypotheses in light of the available spatial data?
Which map (D or F) provides the best spatial representation of the degree of threat to manatees?

<u>Direct threat (collisions)</u>
Prior to obtaining the DRNA boating impacts report, we had used the DRNA boat ramp data as a proxy for identifying areas likely to have high levels of recreational boating. We processed these data in two ways. First, we considered the density of boat ramps (5 km radius moving window) (Maps C & D), assuming that higher boat ramp density would translate to higher watercraft density and, in turn, higher threat of collisions with manatees. Second, we used the simpler approach of calculating distance to nearest boat ramp (Maps E & F), assuming that watercraft density, and thus the threat of watercraft collisions, would decrease with increasing distance form boat ramps.









There are other possible combinations of these data that we could model. These would use the base threat maps produced, but allow other information to increase or reduce the base threat level. For example, threat might be elevated in sheltered bays and river mouths where manatees are known to regularly occur or the threat might only apply where boats co-occur with shallow seagrass. The boat impact study from DRNA provides more direct data on boating impacts to seagrass. These data, however, must also be extrapolated to the full scope for our MPA analysis. This might be possible by interpolating values between the boat density points, but there may not be enough points.

DISCUSSION & REVISIONS

Experts were not satisfied with the boating threat data. Their recommendation was to review and possibly incorporate the EPA Environmental Sensitivity data as an alternative data source. These data include information on fishing activities (recreational, commercial, and subsistence) as well as infrastructure data (boat ramps, marinas, coast guard facilities). They also recommended that the mooring buoy data be removed, because they could not reach consensus regarding their relevance to motorized watercraft threat to manatees. For example, they observed that many mooring buoys are used by sail boats, not motorized watercraft. The ESI data, however, are quite old, so it was determined that these data should be updated wherever possible with the more recent DRNA boat ramp data and our marina data. The DRNA recreation boating data were also used to supplement the ESI data, but the data would be treated as presence/absence (rather than concentration) of recreation boating activity to be more consistent with the ESI data.

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Personal Communications

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