Mapping populations of the threatened staghorn coral (*Acropora cervicornis*) within frequently visited *cayos* of La Parguera Natural Reserve: Focusing management and restoration efforts

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Juvenile fish populations in Acropora cervicornis thickets at Mahimo reef.

Abstract

Coral reefs around the world are in rapid decline due to synergistic effects of local and global scaled stressors. The staghorn coral (*Acropora cervicornis*) has been an important foundation species in shallow water reef environments adding significant structural complexity to habitats. However, this species is now threatened under the Endangered Species Act (ESA) due to the population disappearance and/or significant reduction in reefs all over the Caribbean since late 1980s. In the last two decades geo referencing methods to map diversity indicators have become an essential tool in ecosystem based management and marine spatial planning that aims to protect fish and endangered species essential habitats (Mumby et al. 1995; Ruckelshaus et al. 2008). This tool has also been very effective when orchestrating collaborative efforts between researchers, managers, policy makers, stakeholders, and educative personnel. These collaborative efforts enable conditions for the successful completion of the management cycles. Furthermore, the Endangered Species Act (ESA) provides managers and stakeholders with a reliable policy and legal framework to enforce approved management plans. Here we proposed to produce a comprehensive map of the populations of *Acropora cervicornis*, an ESA protected species, within accessible reefs of La Parguera Natural Reserve (LPNR). This map then can be used in the development and enforcement of effective ecosystem based management strategies for LPNR in collaboration with Puerto Rico's State Environmental and Natural Resources Department (DRNA). This can serve as a mapping model to implement among prioritized management areas of Puerto Rico following the marine spatial planning guidelines and management priorities (DRNA, 2008; NOAA, 2010).

Introduction

Coral reefs at risk

Coral reefs are the most diverse marine ecosystems and have shown dramatic declines in live coral cover. Simultaneously, community phase shifts characterized by algal dominance thought to compromise essential ecosystem functions and services have taken place (Hughes 1994; Ostrander et al., 2000; Wilkinson, 2008). In the Caribbean alone some estimations of this change have suggested an overall loss of 40-50% live coral cover during the last three decades due to the synergistic effects of local and regional scale stressors (Jackson et al., 2014). Global changes can be evidenced in biogeographical patterns of diversity, health, and species interactions. Also, a common sign of reed deterioration is the loss of structural complexity (rugosity). Foundation species play an essential role on maintaining functionality and community structure of the reef biological communities. Scleractinian corals (stony corals) play the essential role of building reef structures where most of the reef biodiversity if found. In this regard, targeting diversity indicators and/or fast growing foundation species in research efforts is of utmost importance to monitor ecosystem functionality and services to human populations like productivity, accretion, and tourism.

***Acropora cervicornis* as a diversity indicator**

Structural complexity and coral zonation are essential aspect of coral reef geomorphologies. *Acropora cervicornis* has been an essential contributor of complex structural framework part of the baseline (or undisturbed) structure of Caribbean coral reef in the geological past (Greenstain et al., 1998). The high degree of diversity of a coral reef system is dependent of the number niches available for specialization of reef taxa and structural complexity as shown in the review by Graham and Nash (2013). As a foundation species, *A. cervicornis* leads reef accretion in many reef habitats including reef crests, back reefs, lagoons, and seagrass beds. This adds to the integrity of nested coastal ecosystems by means of biophysical connectivity. Local studies in LPNR suggest the importance of this coral species on the recruitment of juvenile reef fishes in marginal areas of coral reefs. One of the fastest growing coral species in the Caribbean, *A. cervicornis* can grow up to ten centimeters in linear extension per year in a highly branched fashion. This makes *A. cervicornis* an ideal model for reef restoration techniques as evidenced by successful restoration projects because it grow fast and creates a complex tridimensional structure that could potentially serves as essential fish habitat (Ex. Quinn and Stennet, 2004). This foundation species can rebound after mass mortalities and cause what has been referred as "reverse phase shifts" in relative small ecological time scales (Idjadi et al. 2006). In this regard, some coral reef researchers address the species as a "weedy coral". However, the duration of these recovery trends can be highly ephemeral due to the vulnerability of recovering populations to bleaching, diseases, competitive interactions, and physical disturbances (Quinn and Kojis, 2008; Jackson et al., 2014; Hughes

1994). The Caribbean acroporids have shown dramatic declines in abundance, distribution, and cover % since the late 1970s due to the epizootic disease event of White Band Disease (WBD) (Weil et al. 2002; Jackson et al. 2014). Furthermore, the massive *Diadema antillarum* die-off in the 1980s helped to substantially increase space competition with algal populations. Hurricanes impacted reefs and further compromised the ability of these populations to recover (Jackson et al. 2014). Even though fragmentation and subsequent growth is an essential life history trait of the acroporids species, the synergistic effects of all these stressors have maintained the species under the threatened species status.

Objectives

With this project we aim to contribute in the design of a zoning plan to be included in an updated management plan for LPNR. To achieve this we have developed the following objectives:

1) Illustrate present geographical extent distribution of *A. cervicornis* within La Parguera Natural Reserve (LPNR) represented as polygons on a coordinate system base map.
2) Provide quantitative estimations on *A. cervicornis* thickets area and habitat occupancy percentage.
3) Provide recommendations for a restauration plan of the populations of *A. cervicornis* in LPNR.

Methodology

In 2009, federal environmental agencies produced a presence/absence map of acroporids within LPNR (Figure 1). This map was used as a guide to focus field work. The polygons produced during this project will be compared with Figure 1 to identify areas of recent *A. cervicornis* development. We used three layers to produce our map: a satellite image of LPNR *cayos*, one for the polygons of *A.cervicornis*, and one for a 10 meter buffer around polygons.

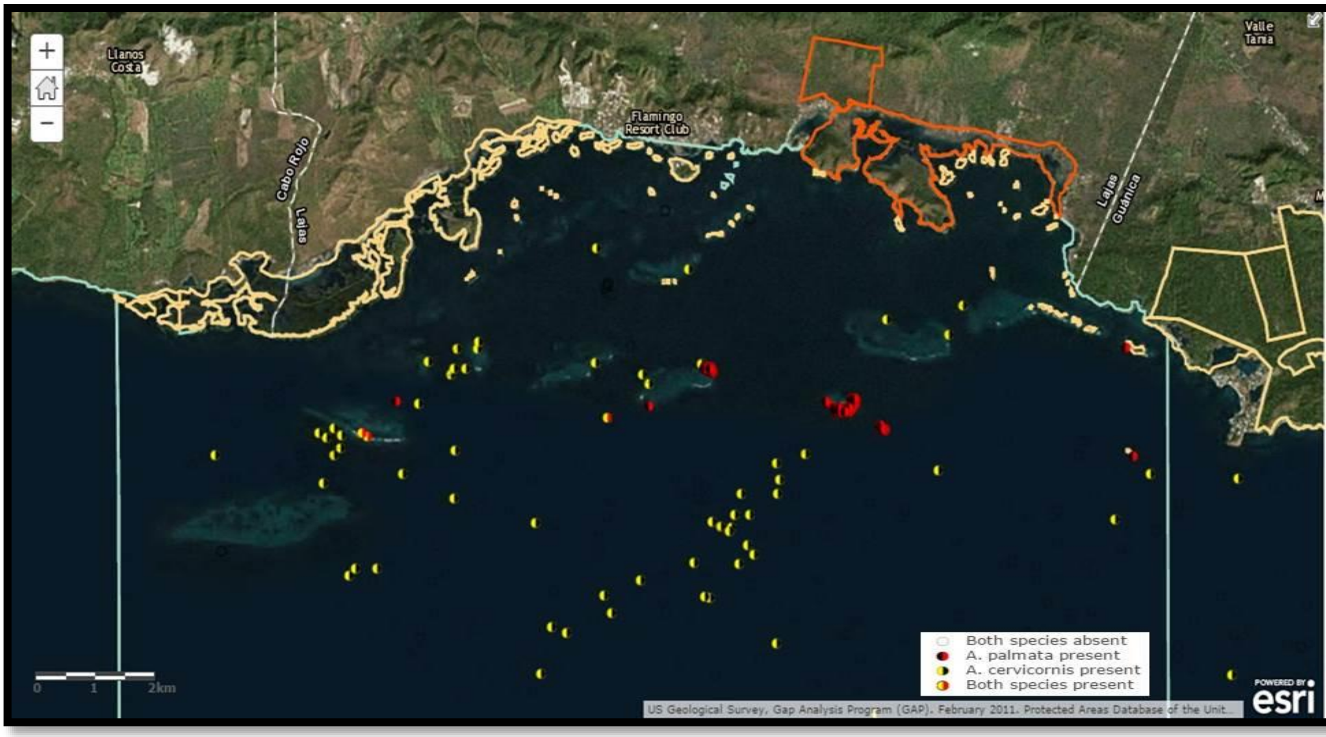

Figure 1. LPNR management and law enforcement is currently under Puerto Rico's State Natural and Environmental Resources Department (DRNA) jurisdiction (clear brown and blue lines). Yellow and red points represent presence of *Acropora cervicornis* and *Acropora palmata*, respectively. This map will be used as an exploration guide to create polygons where *A. cervicornis* population attributes will be raised. Data on map gathered by Caroline Rogers (USGS, 2009). US Geological Survey, Gap Analysis Program (GAP). February 2011. Protected Areas Database of the United States (PADUS), version 1.2. | DigitalGlobe, GeoEye, CNES/Airbus DS | Florida Fish and Wildlife Conservation Commission - Fish and Wildlife Research Institute | Esri, HERE, DeLorme

To illustrate each cayo and the extent of *A.cervicornis*, we created a Map using ESRI press's ArcMap with several polygons over a georeferenced OLI_PARGUERA_2006 multispectral satellite image as a base. In order to calculate total coverage area of *A. cervicornis* patches, we created two shapefiles composed of multiple polygons each. One shapefile contained the polygons corresponding to the total Potential Habitat area for *A. cervicornis* of each cayo, while the second shapefile contained the polygons corresponding to the measured patches of *A. cervicornis*. A additional third shapefile was created representing a 10 m buffer around each measured patch.

To create the potential habitat polygons we digitized the back reef areas of the select cayos using ESRI ArcMap software's draw toolset. After digitizing each individual polygon and saving it as a new feature, we then merged the polygons into a single shape file or feature class using the merge tool in the ESRI Data Management tool box. Polygons representing the current patches of *A. cervicornis* at each cayo were build off of a series of GPS waypoints taken in the field by circumnavigating each patch with a Garmin e-trek series GPS, downloaded, organized and saved as .txt files and added to the OLI_Parguera basemap as X-Y data. Individual polygons were then merged into a single shapefile “Cayos”. Individual area coverages were calculated via attribute table values calculated by the program, while the final coverage area of both datasets was computed using the model builder tool in ArcMap by using the “Potential_Habitat” and “Cayos” feature classes as input data. The program then calculated the total area of all the cayos and potential habitat, and then coverage area.

Our recommendations for a restoration plan where based on habitat occupancy and the area of potential habitat of each *cayo*, prioritizing those *cayos* with little *A. cervicornis* habitat occupancy and large back reef areas. However, it should be noted that potential habitat for A. cervicornis can be related to additional factors like storm frequency, temperature regimes, herbivory, and sediment suspension/resuspension. These additional factors can be assessed with additional analyses and may be hard to predict due to the high variability of baseline data. Some populations have been observed at depth of 15 meters (unpublished observation). These populations where not assessed in this project due to logistical constrains like accessibility and low direct vulnerability to human activities.

Results and Discussion

Polygons and Areas

A total of **11 polygons** where created in **6 frequently visited *cayos*** of LPNR, representing **46,357m^2** of back-reef area with *Acropora cervicornis* development (Figure 2). These “*cayos*” are known as **Mahimo, Caracoles, Enrique, Mario, San Cristobal, and Media Luna**. Coral reefs driving the accretion of these *cayos* occur between one and three miles from shore.

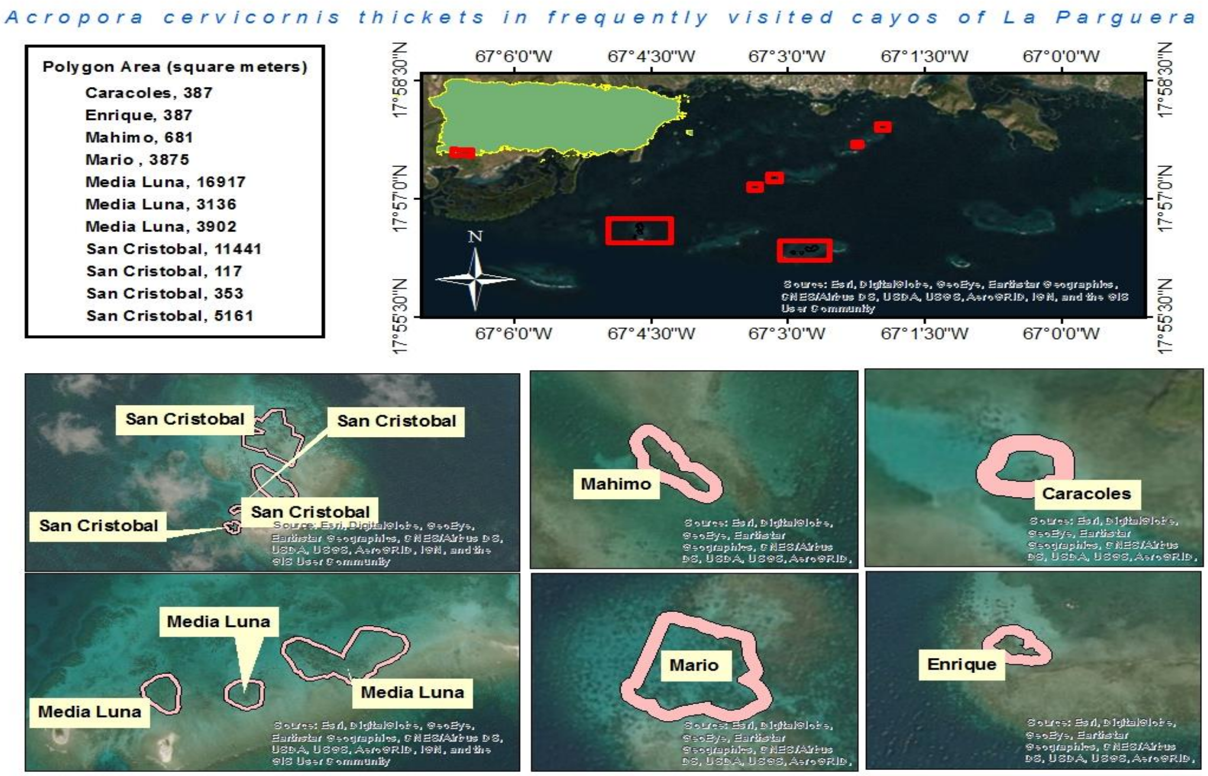

Figure 2. Projected polygons and their area in LPNR *cayos*.

Table 1. Area in meters squared of each created polygon.

Polygon	Area(m2)
St. Cristobal(Channel end)	117
St. Cristobal(Channel)	353
Caracoles	387
Enrique	387
Mahimo	681
Media Luna(2)	3136
Mario	3875
Media Luna(1)	3902
St. Cristobal (West)	5161
St. Cristobal (East)	11441
Media Luna(3)	16917

Potential habitat occupancy and restoration recommendations

On average, polygons occupied **10%** of visited back reef potential habitat. This suggests that the staghorn coral populations could benefit from conservation and restoration efforts due to low habitat occupancy. A substantial supporting fact could be added to this claim by visiting all *cayos* and providing the proportion of *cayos* with *A.cervicornis* to those without the species. When comparing our results with the presence/absence map (Figure 1), *A. cervicornis* was found in 3 *cayos* where the USGS map did not displayed presence of the species. These *cayos* where Mario, Caracoles and Mahimo, some of the most frequented by users of LPNR. Furthermore, Mario had the back reef area with highest *A.cervicornis* habitat occupancy where the overlaid polygon occupies **23%** of the back-reef area (Figure 3). In this context, given that the staghorn coral has disappeared from most Caribbean reefs, it is reasonable to argue that even though the average habitat occupancy fell below 20% for visited reefs of LPNR, this Natural Reserve hold some of the largest extant *A.cervicornis* populations in the southwest coast of Puerto Rico.

An important aspect to justifying further marine spatial planning efforts is the state of a population in respect on its original state. Restoration efforts are strategically proposed when present conditions are incorporated into the selection criteria of a restoring location. Coral transplants survivorship is one of the key parameters to measure the success of restoration efforts. Therefore, we have identified back reefs with small existing *A. cervicornis* population as areas where promoting thicket growth can be a well spend effort. Media Luna had the biggest polygons suggesting the suitability of this back reef environment for acroporids growth. This shallow water back reef offers high water flow and is more exposed to offshore larval transport than closer reefs to shore. However, Media Luna exhibits small potential habitat occupancy given the large back reef area and this is probably related to exposure to frequent storm swells. Nevertheless, Media Luna offers a large back-reef area where potential sites for coral transplantations can be evaluated in more detail. Areas that offer moderate swell protection like behind or in between patch reefs with massive coral species could be selected. The high water movement of this environment could be essential for transplants survivorship if fragments are well attached.

Given the large habitat occupancy at Mario and San Cristobal, fragments to replenish smaller populations in nearby reefs could be obtained from these populations. Also, as a qualitative fact, Mario and San Cristobal showed a high diversity of *A. cervicornis* morph types, suggesting high genetic variability, a well-recognized positive characteristic on enhancing population adaptation and survivorship. Small A. cervicornis thickets where observed in Enrique, Caracoles, and Mahimo, the closest to shore reefs identified in this project as *A. cervicornis* habitat. Regardless of their size, these populations may be of essential importance in promoting biophysical connectivity between the mangrove forest in the shore and the coral reef environments of the *cayos*. Less than a kilometer from shore, the Mahimo thicket was observed to be home of hundreds of juvenile snappers and grunts. Promoting expansion of these thickets could be a great effort to improve fish transport among reefs and recruitment. However, there are other special considerations that must be taken into account before evaluating this, like present patterns of recreational usage and future sustainable economies for LPNR (Ex. ecotourism and education).

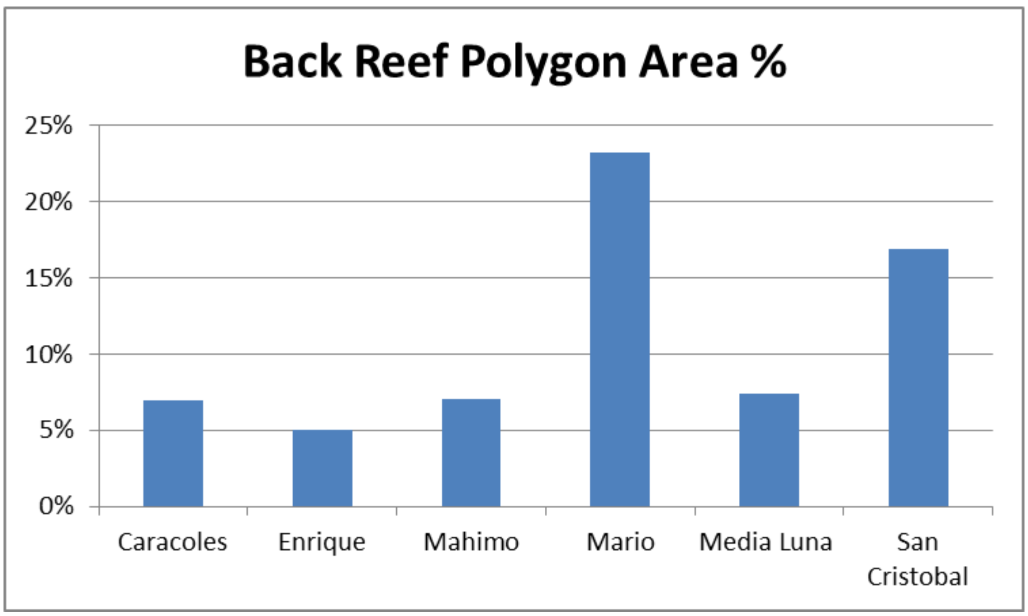

Figure 3. A.cervicornis back-reef potential habitat occupancy. These percentages where obtained dividing the polygons area for each *cayo* by the back-reef area of the *cayo*.

Implications for Management

Attracted by the tropical scenery, mangrove shading, and proximity to shore, thousands of tourists visit these LPNR *cayos* every year. Caracoles, Enrique, and Mahimo are among the most visited of these. Some recreational activities represent significant disturbances to the coral reef and associated ecosystems by means of overfishing, sediment resuspension, oils, trash littering, and physical damage. During some activities, the carrying capacity of these *cayos* is highly surpassed by hundreds of boats anchored in areas nearby *A.cervicornis* growth (Figure 4) having direct damaging effects of seagrass beds and associated fauna. These disturbances are among local stressors that have profound implications for management due to the specificity of the source.

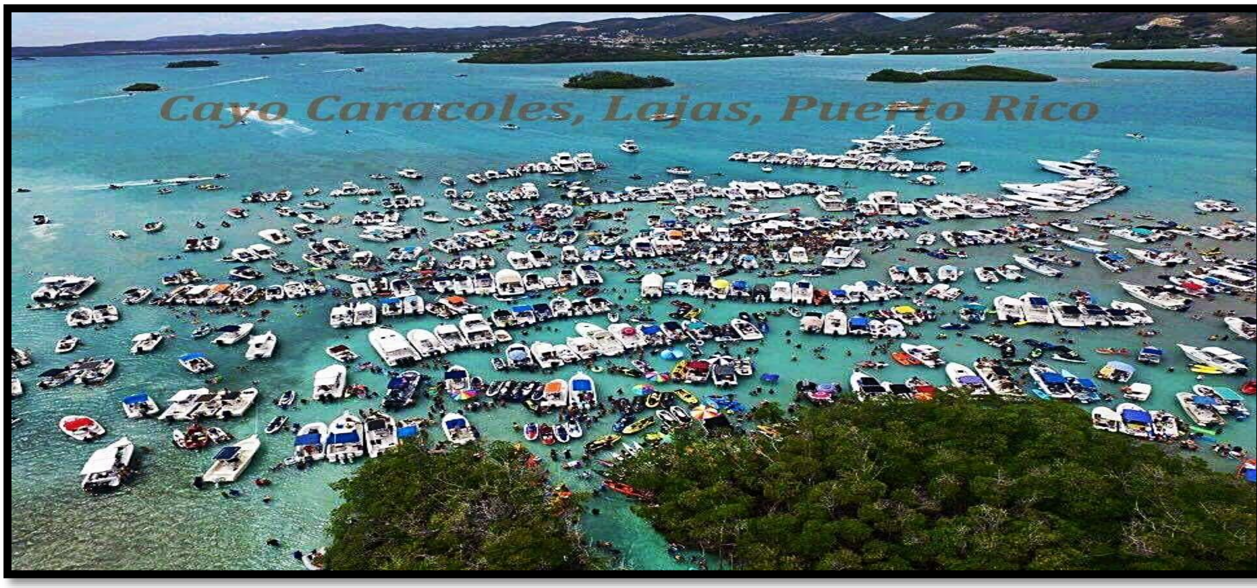

Figure 4. Recreational activities in Caracoles, LPNR, occur less than a kilometer from obtained polygons (Caracoles and Mahimo). Management actions are crucial to comply with the objectives and purposes of a Marine Protected Area (MPA) designation.

Past government responses to ecological issues set an important baseline to consider when developing a new strategic approach to deal with such issues (Olsen et al. 2011). Here we address accessible reefs as the most visited by users of LPNR (recreational and commercial fishermen, diving businesses, boat owners, researchers, and others). Populations of endangered species within these areas are at mayor risk of human disturbances such as fishing pressure and physical breakage. The Department of Natural and Environmental Resources has deployed 38 mooring buoys in the last decade. However maintenance has been challenged by economic pressures and lack of personnel. Management strategies such as **labeling, anchoring mooring deployments, and no-take zonation** are necessary but not sufficient to conserve these species and increase the likelihood of adaptation to global climate change (Graham et al. 2015). Therefore, a precise map and description on the most significant populations of these species provide an essential tool to initiates these necessary actions. Government action towards these needs is mandatory to comply with the foundation laws of environmental agencies. According to subsection (j) from article (5) in Law #23 of June 20, 1972, the **secretary of the DRNA** has the faculty and responsibility to initiate and/or support investigations to obtain information on the population, distribution, habitat needs, limiting factors, and other ecological data to determine necessary conservation measures to sustain the survival of wildlife. Also, according to subsection (8) from article (5) in Law #1 of June 29, 1997, the **DRNA Law Enforcement Unit** has the right and responsibility to interfere with issues regarding dispositions stated in approved laws, regulations, and management plans related to the conservation of natural resources. The legal framework to sustain these arguments can be found in the **Endangered Species Act** (ESA) and the recently approved **Coral Reef Regulation Puerto Rico**’s (appendix).

Conclusions

Despite the overall decline and local extinctions of the staghorn coral across the Caribbean basin, LPNR still hosts an important population of this threatened species. We obtained polygons that represent *Acropora cervicornis* thickets in six cayos with variable size, exposure, and proximity to other ecosystems. However, judging by our area analyses these populations are not occupying their potential habitat as they might have during past pristine conditions. Given the fast growth and ecological importance of Acropora cervicornis, management actions with conservation and restoration implications are feasible and well justified. We argue that reefs with highest habitat occupancy should be a main focus of conservation and no-take zonation. Large back reef areas with existing small populations should be targeted for restoration efforts, as well as those areas close to mangrove-seagrass ecosystems. Human activities have been poorly managed, and there should be long-term plans to create harmony between economic and conservation needs to promote a sustainable socio-ecological system.

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