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Elkhorn Coral Distribution and Condition throughout the Puerto Rican Archipelago

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Abstract. We estimated 673 km^2 of potential habitat for *Acropora palmata* in Puerto Rico using GIS and measured the distribution, abundance and condition with a random sampling approach at six sites (3 east and 3 west coast MPAs). Average density ranged from 0.2 to 9.8 colonies/100m^2 and was highest on west coast sites (Rincón and Cabo Rojo) and these sites showed lower predatory snail (*Coralliophila abbreviata*) prevalence and density. Overall, the prevalence of white band disease was low (2.4% of colonies) yet variable and recent mortality due to diseases was highest in Culebra. Mortality caused by boring sponges (*Cliona tenuis*) was only observed at west coast sites. Nine plots were established in 2007 for long-term monitoring of demographic variables using individually tagged colonies. The results indicate that spatial variability must be considered when assessing trends at the regional level in order to clearly understand population status and responses to management actions.

Key words: Puerto Rico, *Acropora palmata*, spatial distribution

Introduction

In 2006, the corals *Acropora palmata* and *A. cervicornis* were listed as threatened species under the US Endangered Species Act (NOAA 2006), underscoring the need for assessment of status and recovery of their populations. An important realization during the assessment and listing process was that trends in the populations of Puerto Rico and demographic information necessary for modeling changes at the population level was unavailable.

In Puerto Rico the spatial extent of Elkhorn coral (*A. palmata*) and its condition throughout the archipelago was described by Almy and Carrión (1963) and Goenaga and Cintrón (1979) who reported most of the shallow reefs surrounding the island as dominated by *A. palmata*. A few sites described by Goenaga and Cintrón (1979) have been studied over time in Culebra, Fajardo, Guánica, Mona Island and La Parguera, yet no comprehensive monitoring directed towards this species is currently in place. In order to assess *A. palmata* population status this study examines the distribution at large spatial scales combined with localized demographic surveys to determine coral colony condition and existing threats.

Puerto Rico contains the greatest extent of Elkhorn coral in the US Caribbean. The main island of Puerto Rico has been identified as within the genetic population of the eastern Caribbean while Mona Island has been proposed as a mixing zone for the eastern and western populations for the species (Baums et al. 2005). This makes the area an important region to understand population dynamics and provide data towards evaluating recovery of the species.

The goal of this project was to determine the current distribution and condition of Elkhorn coral in Puerto Rico, to provide a basis to assess population status and trends in the archipelago. The first objective was an island wide calculation of the potential habitat for the species. Secondly, a subset of the area was sampled in order to determine the presence and condition of *A. palmata.* Finally, long-term demographic monitoring was initiated utilizing permanent plots.

Materials and Methods

A geographical information system (GIS) was used to create a spatial database in order to delineate the potential habitat of Elkhorn coral around all Puerto Rico. Potential habitat for Elkhorn coral was defined as the areas where occurrence of the species is possible, namely areas of hard substratum to 15m depth. Bathymetric and benthic habitat (NOAA 2001) layers were used to select

areas between 1 and 15m of hard-bottom habitat. These areas were stratified by depth into high probability of encountering Elkhorn in shallowest depths (0-5 m), medium probability in mid depths (5-10 m) and low probability in deeper regions (10-15 m). All map calculations were conducted at 50m cell size. Benthic habitat maps were used to extract areas of unconsolidated sediments and submerged aquatic vegetation. Some areas of habitat classified as 'unknown' due to low water clarity in the aerial photos were included if they were located in areas of suitable depths.

In order to quantify Elkhorn abundance, areas of potential habitat with a high probability of encountering Elkhorn coral were chosen within 6 marine protected areas (MPA) on the east and west coast of the island. The study focused on these MPAs because of their importance to coral reef conservation and to provide an island-wide perspective, although they may not represent all areas of potential habitat. Arrecifes de la Cordillera Natural Reserve (NR) is located off of Fajardo on the northeastern coast of Puerto Rico and includes multiple cays and reefs, while Canal Luis Peña NR in Culebra and Bahías Bioluminiscentes de Vieques NR are located along the eastern coast. Tres Palmas Marine Reserve (MR) in Rincón and Punta Guaniquilla NR in Cabo Rojo are on the main island's western coast, while Arrecifes de Tourmaline NR is part of an offshore reef system located 9.5 km west of Puerto Real, Cabo Rojo.

Within the potential habitat (high probability, <5m depth hardbottom) of each MPA randomly chosen points were selected in GIS (ArcMap 9.1 and Hawth Tools extension) and uploaded to a handheld GPS. In the field a leaded line with surface buoy was used to mark the randomly chosen point to center the $100m^2$ survey area. At each survey area the presence of *A. palmata* and dead standing skeletons within the $100m^2$ was noted by delimiting the area with a floating line (5.6m) used as radius of the circular plot. When live *A. palmata* were present the number, size (maximum length, width and height) and percent live coral cover of each colony was measured for those colonies with their center within the survey area. Colonies less than 50 cm in minimum length were not quantified in these surveys. A Live Area Index (LAI) was calculated (length*width*% live/100) for each colony as an estimate of total coral tissue. Elkhorn colony measures were compared between sites with non-parametric statistical methods. In addition, colony condition variables were assessed including bleaching, disease and predation by invertebrates.

Data on the distribution and condition of *A. palmata* were then used to establish permanent long-term demographic monitoring stations following the protocol of Williams et al. (2006). These sites have been sampled semi-annually since October 2007. All colonies within a $150m^2$ circular plot were measured, photographed, and 12 randomly chosen colonies were permanently tagged for long-term monitoring to quantify their survivorship, growth and changes in condition. At three MPA sites three circular plots (150 m^2) were established with permanent markers.

A size frequency distribution based on classes determined by amount of live tissue was used to show population structure patterns. Colonies between 60 cm^2 and 1,600 cm^2 have low-reproductive potential, while colonies below 15–60 cm^2 are not reproductively active (Soong and Lang 1992). Based on these estimates, large (presumably adult) colonies were considered to be those larger than reproductive size (1,600 cm^2), medium those below minimum reproductive size (50–1,600 cm^2), and small those not expected to reproduce (<50 cm^2). The LAI of tagged colonies per plot was compared between baseline and month 6.

Results

The island-wide potential habitat for Elkhorn coral was estimated at 673 km^2 (67,354 ha). This was classified into areas of high (16% of total area), medium (30%) and low (54%) probability of encountering the species. The area of potential habitat with the highest probability of finding Elkhorn coral was 106.5 km^2 (10,651 ha). The proportion of high probability potential habitat area in the 6 MPAs varied inversely to total MPA size (Table 1).

Table 1: Sampling areas in MPAs on the east and west coast of Puerto Rico and the percent of submerged area (Area) which is considered potential habitat (high probability) for *A. palmata* within each MPA

	Marine Protected Area	Area (ha)	% Potential Habitat
WEST	Tres Palmas (**TP**)	83	62.4
	Arrecifes Tourmaline (**AT**)	7,269	1.3
	Punta Guaniquilla (**PG**)	1,947	2.7
EAST	Arrecifes de la Cordillera (**AC**)	10,082	2.5
	Canal Luis Peña (**CLP**)	633	12.6
	Bahías Bioluminiscentes de Vieques (**BB**)	7,962	1

Elkhorn density and colony measurements were conducted at 431 randomly selected survey areas within the high probability potential habitat of 6 MPAs from December 2006 through October 2007. Overall 30.7% of all points sampled had live *A.*

palmata colonies, yet this varied from 4% at Punta Guaniquilla NR to 73% at Arrecifes de Tourmaline NR showing significant differences in the distribution of live *A. palmata* (Fig. 1). Overall 13.7% of points sampled had *A. palmata* dead standing skeletons or rubble indicating the species used to occur in these areas. This also varied greatly from 0% at Tres Palmas MR to 42% in Arrecifes de la Cordillera NR. Colonies were absent in 27.5% of all points, ranging from 13% at Arrecifes de Tourmaline to 50% at Arrecifes de la Cordillera. Areas where *A. palmata* was absent were gorgonian dominated hard-bottom or uncolonized pavement with sand.

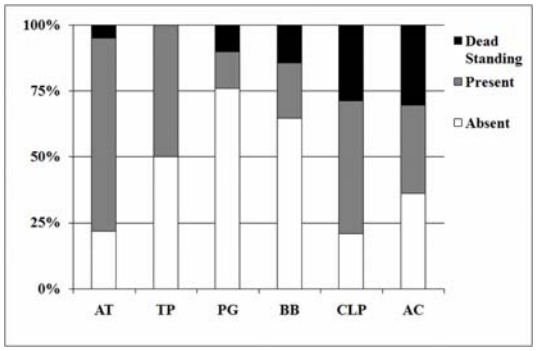

Figure 1: Presence of Elkhorn coral within the high probability potential habitat areas of: **AT** = Arrecifes de Tourmaline (N=60), **TP** = Tres Palmas (N=56), **PG** = Punta Guaniquilla (N=29), **BB** = Bahias Bioluminiscentes de Vieques (N=48), **CLP** = Canal Luis Peña (N=100) and **AC** = Arrecifes de la Cordillera (N=138).

Colony density varied greatly and ranged between 0 and 52 colonies/100m^2. The greatest abundance of *A. palmata* was observed at two west coast MPAs (9.8 colonies/100m^2 for Arrecifes Tourmaline NR and 7.1 colonies/100m^2 for Tres Palmas MR) where the overall mean was significantly higher (Kruskal-Wallis test p=0.00) (Fig 2). On average the largest colonies were observed at Tres Palmas MR and Arrecifes de Tourmaline NR while the greatest proportion of smaller sized colonies (50-99 cm length) was seen at Canal Luis Peña NR.

A total of 1,387 colonies were quantified and measured throughout all MPAs. The number of colonies assessed per study site varied from 5 at Punta Guaniquilla to 586 at Arrecifes de Tourmaline. Due to the low number of colonies available in Punta Guaniquilla NR and Bahías Bioluminiscentes de Vieques NR the data from these areas is not included in further analyses.

Percent live tissue cover per colony averaged highest at Arrecifes de la Cordillera NR (87%) followed by Tres Palmas MR (77%) and was lowest at Canal Luis Peña NR (61%). Mean LAI varied between 1.4 and 14.9 m^2 per survey area. Colonies at west coast sites showed significantly higher LAI (Kruskal-Wallis test p=0.00) over east coast sites (Fig 3).

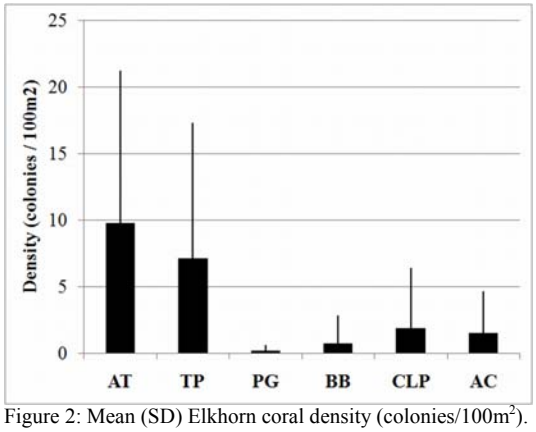

Figure 2: Mean (SD) Elkhorn coral density (colonies/100m^2).

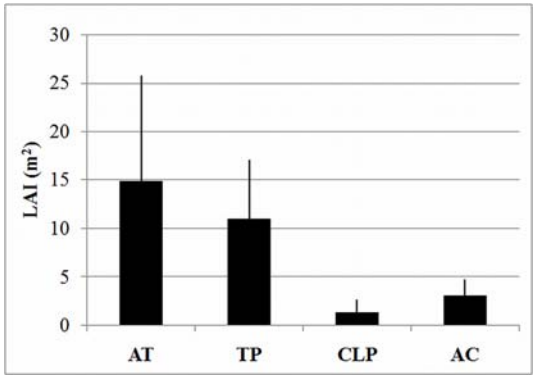

Figure 3: Mean (SE) live area index (LAI) per survey area (m^2) for survey areas where *A.palmata* was present.

Infestations of corallivorous snails (*Coralliophila abbreviata*) were observed on 3% of all colonies although this ranged from 0.9% in Arrecifes de Tourmaline NR to 10.6% at Canal Luis Peña NR. Snail occurrence rates were higher on the east coast which had lower Elkhorn densities and smaller colonies. Average number of snails per colony ranged from 2.6 for Arrecifes de Tourmaline NR to 5.1 at Arrecifes de la Cordillera NR. The frequency and number of snails was highest at Canal Luis Peña NR and Arrecifes de la Cordillera NR and the occurrence was inversely related to the density of colonies over all sites sampled.

Disease was observed on 6.7% of colonies averaged over all sites (range from 4% at Tres Palmas MR to 9% at Arrecifes de Tourmaline NR) and most of the diseased colonies were classified as such due to patchy necrosis (white pox disease). White band disease (WBD) affected 2.4% of all colonies and was most prevalent in Arrecifes de la

Cordillera NR (4.7%) and Canal Luis Peña NR (1.6%) while only 1% occurred at Arecifes Tourmaline NR and none were observed at Tres Palmas MR. Partial bleaching (<20% of colony) was observed in Tres Palmas MR (3 colonies) and Arrecifes de Tourmaline NR (2 colonies) on the west coast. Recent mortality estimates ranged from 0.1% of the colony to 40%. The greatest percentages of the colony affected by recent mortality were attributed to competition with the encrusting sponge *Cliona tenuis* (only at west coast sites) and diseases.

Those MPAs with lower densities of live *A. palmata* (Punta Guaniquilla NR, Canal Luis Peña NR and Bahías Bioluminiscentes de Vieques NR) were not considered suitable for permanent long-term monitoring. This was mainly due to the limitations of the protocol for demographic monitoring (Williams *et. al*. 2006) in which areas with low density of *A. palmata* or depths less than 2 m are unsuitable. Three permanent monitoring plots were established at each of three MPAs (Arrecifes Tourmaline NR, Arrecifes de la Cordillera NR and Tres Palmas MR) in October of 2007 for demographic purposes. The frequency distribution of size classes in the permanent plots showed a greater proportion of small colonies in Arrecifes de la Cordillera (Fig. 4).

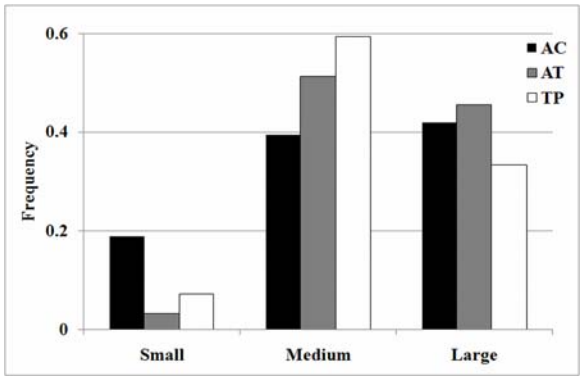

Figure 4: Frequency distribution of all colonies by size classes at long-term monitoring plots in AC (N= 117), AT (N=156) and TP (N=138). Size classes based on amount of live tissue: Small < 50 cm^2, Medium 50 cm^2 – 1,600 cm^2, Large > 1,600 cm^2.

After six months, three (2.7%) permanently tagged colonies were dead and 18 (16.7%) were unaccounted for within the permanent plots. No significant changes in live tissue cover were observed for the colonies that remained. The mean LAI for each plot decreased at Arrecifes de la Cordillera over the first six months of sampling (Fig. 5).

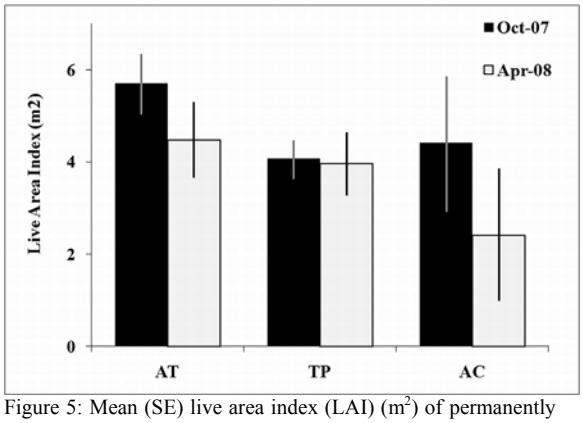

Figure 5: Mean (SE) live area index (LAI) (m^2) of permanently tagged colonies per plot over two sampling periods.

Discussion

In this study we estimate that potential Elkhorn coral habitat occurs in an area approximately 673 km^2 around the Puerto Rican archipelago. In order to improve this estimate greater resolution bathymetric and habitat maps are necessary to refine the scale of potential habitat. Ground-truthing of additional sites where it was documented in the past (Goenaga and Cintrón 1979) will help improve the estimate further accounting for spatial variability as this species is known to be patchy in distribution.

Within the 6 MPAs the proportion of area where Elkhorn coral was present (30% of high probability potential habitat) was lower than an island-wide estimate of 88% conducted during the late 1970's (Weil et al*.,* 2002), although methods differ. On the eastern coast the presence of Elkhorn was observed at 37% of sites (Weil et al*.,* 2002) which is comparable to this study's estimate of 36% pooled for three east coast sites. Nonetheless, total loss in Elkhorn coral was evidenced in 13.6% of the random survey areas where only dead standing skeletons were present (range 0% - 42%) which can be extrapolated to an estimate of 15 km^2 island-wide and is supported by the observation of large thickets of dead standing Elkhorn.

The proportion of random survey areas where live Elkhorn was present varied greatly among MPAs (14% - 73%) and the higher estimate from Arrecifes Tourmaline is comparable to results obtained by Mayor et al. (2006) (74%) in St. Croix, USVI. However, the maximum depth sampled in Puerto Rico was 5 m and in St. Croix it was 10 m. The overall density from this study (3.3 colonies/100 m^2) was higher than St. Croix (1.6) and Venezuela (3.1) (Mayor et al*.,* 2006; Zubillaga et al*.,* 2007), however comparison of density estimates among studies is troublesome due to difference in methods and the limits of areas surveyed.

On average the Elkhorn populations within the MPAs on the east coast of Puerto Rico seem to be in relatively poorer condition due to lower density, size, live coral cover and higher rates of disease, recent mortality and predation by snails. Canal Luis Peña, Culebra had the lowest mean live coral cover per colony and the smallest sized colonies with resulting low mean LAI. Arrecifes de la Cordillera had the highest mean live tissue cover per colony of all sites but it lacked large sized colonies which reduced the mean LAI for the site. Since small colonies make up a greater proportion of the population at east coast sites this may reduce their ability to withstand bleaching, disease and predation impacts as less live tissue is available to be lost.

White band disease (WBD) was observed in 2.4% of all colonies yet the greatest proportions were observed in east coast sites of Puerto Rico. In St. Croix the overall prevalence of WBD was 3.2% (Mayor *et. al.,* 2006) while in Los Roques, Venezuela it varied between 0.4 and 4.7% (Zubillaga *et. al.,* 2007) suggesting that Elkhorn coral threats demonstrate high variability within geographical regions, although temporal factors may also affect the patterns observed.

The overall proportion of colonies with snails averaged 3.7% (range 0.9 to 10.6%) which is lower than previous reports for Puerto Rico (e.g., 18%, Bruckner *et. al.,* 1997), yet this is highly variable. At east coast sites colonies had groups of 10 to 18 snails while the west coast sites had occurrences of less than 6 snails per colony. Mean number of snails per colony was 5.1 at Arrecifes de la Cordillera, higher than the 3.7 estimated for La Parguera (Bruckner 2000).

Long-term monitoring for Elkhorn coral in Puerto Rico initiated in 2007 showed a decrease in LAI for colonies tagged in Arrecifes de la Cordillera. Although no significant changes in mean percentage of live tissue cover were detected, the loss of 12 colonies at this site reduced total plot LAI. The loss of whole colonies was caused by the unusually large swell event that occurred during March of 2008 with long period waves reaching up to 12 m in height (National Weather Service, NOAA). Other sites also had detached and broken colonies, yet impact was most notable in northern sites of Arrecifes de la Cordillera and at Tres Palmas MR the number of loose fragments was lower than at other sites.

The potential habitat for *A. palmata* calculated for the Puerto Rican archipelago is a first step towards better understanding the population's spatial and temporal trends. As a population declines, a combination of reduced extent and density is expected, yet extrapolating results from a few sites can be misleading. Our results suggest differences in the occurrence, distribution and condition over the scale of Puerto Rico. The method used to evaluate the distribution of Elkhorn within MPAs provides a spatially explicit baseline upon which changes can be evaluated, which in combination with the demographic monitoring will enhance our understanding of population dynamics of Elkhorn coral in the Puerto Rican archipelago.

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