Status of *Acropora palmata* in Curaçao: comparison with Florida Keys

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Abstract

Monitoring of *Acropora palmata* in Curaçao was initiated in 2006 to provide comparison for monitoring in the Florida Keys begun in 2004. Both areas were impacted by hurricanes shortly after monitoring began allowing us to compare the population responses to these disturbance events. Post-hurricane surveys of fixed 150m^2 study plots in Curaçao (2009) and Florida Keys (2006) revealed loss of approximately half of the live *A. palmata* tissue in both regions. Curacao *A. palmata* colony abundance has increased by 27% in the year following the hurricane whereas Florida Keys populations have gradually declined since the hurricane. Surprisingly, disease prevalence is greater in Curaçao compared to the spring surveys in the Florida Keys. Both corallivorous snails and three-spot damselfish are less prevalent among *A. palmata* colonies. This report is a preliminary look at the observations made in Curaçao as compared to the Florida Keys data. Both projects are planned to continue for the near future.

Project Background and Approach

Acropora spp. populations throughout the Caribbean have declined by greater than 90% since the 1980s. The extent of decline and current status of the population varies regionally from local extirpation to areas where scattered but vigorous patches of the population remain. The Florida Keys population lies on the more affected end of that spectrum (Bruckner 2002; Miller et al. 2002), and although Curaçao has suffered major declines (Nagelkerken and Nagelkerken 2004), higher genotypic richness and anecdotal reports suggest that it may harbor more resilient populations (Bruckner 2002; Baums et al. 2006). We use demographic monitoring data from permanent plots in both regions to evaluate this hypothesis of greater resilience in Curacao.

A demographic monitoring study of Florida Keys *Acropora palmata* began in 2004 following an established protocol (Williams et al. 2006). A comparable study of the *A. palmata* population in Curaçao was implemented in 2006 (Kramer et al. 2009) to compare annual population trends for a presumably more robust reference population. Three fixed 150m^2 study plots were established at haphazardly selected intermediate-density *A. palmata* stands on three reef sites along the southern coast of Curaçao in April 2006. Study Plots have been monitored annually to document trends in abundance, recruitment (asexual and sexual), the prevalence of disease, corallivorous snail, *Coralliophila abbreviata* (referred to simply as 'snails' from here), and the territorial damselfish *Stegastes planifrons* (referred to simply as 'damselfish' from here). These trends were compared to data collected using the same protocol from fifteen plots established in 2004 in the upper Florida Keys (Table 1).

All *A. palmata* colonies in the study plot were mapped using the bearing and distance from a central stake and measured for length, width and height and % live tissue cover of the colony was visually estimated. A subset of approximately 12 colonies in each plot was randomly selected (or all colonies if fewer than 15 were present at the start) and tagged for fine-scale observations of various conditions/threats (e.g. recent mortality, snail feeding scars, disease, bleaching, *Cliona* sp. sponge infestation). Snail and damselfish presence and abundance were also assessed for the tagged colonies. Disease prevalence and the prevalence of snail- or damselfish- occupied colonies are based on the random subset of tagged colonies within each plot. The diseases were classified during surveys as one of three types described for acroporid corals (Williams et al. 2006): white band disease (WBD), white pox (WPx) and rapid tissue loss (RTL). Total prevalence was examined for all three conditions pooled ('white disease', as other studies often do not distinguish between the disease types or the distinction varies between surveyors) and for WBD alone (its published description (Gladfelter 1982) and field-observed signs are more distinct than the other two conditions).

At return annual surveys all colonies within the study plots were matched with those present at the previous survey. New colonies were mapped as 'recruits', and those missing were recorded as dead. In some instances, conditions prevented the matching of all colonies, so only the net change in number of colonies could be determined. In 2008, the tagged colonies from all Curaçao plots were surveyed, but complete surveys of the remaining (untagged) colonies could only be completed at plot BB2, SM3 and SQ3 due to weather constraints.

Small biopsy samples were collected from all tagged colonies in Curacao in 2006 (and Florida Keys in 2005) for multi-locus genotyping to describe the clonal structure of the study plots. Samples were analyzed at Penn State University utilizing the microsatellite markers developed by Baums et al. (2005).

Analysis

The mean of the three measured colony dimensions was used as an index of colony size. Live tissue cover was estimated as a 'live area index' (LAI) by squaring this mean colony dimension then multiplying this area by the field estimate for '%live' for that colony. LAI was summed for all colonies in a plot. Colony abundance is compared as the total number of colonies in each 150m^2 study plot. Both Curaçao and Florida Keys were impacted by hurricanes over the course of the study. In addition to examining contemporaneous temporal trends in LAI, # of colonies and colony average dimension (Fig. 1), we also provide graphical analyses of the trends temporally shifted to align the hurricane impact (Fig. 2). In Curaçao, Hurricane Omar impact occurred in fall 2008 (Year 0) and in Florida Keys four hurricanes impacted the Florida Keys between July and November of 2005 (Year 0). It should be noted that year 0 surveys were conducted prior to the impact in Curaçao and after the first 2005 hurricane (Dennis) but before the other 3 hurricanes (Katrina, Rita and Wilma) passed the Florida Keys.

Results

Since 2006, there has been a 46% reduction in *Acropora palmata* live tissue area (LAI) at monitored sites in Curaçao, Netherlands Antilles (Fig. 1a). The majority of this decline was likely associated with fragmentation from hurricane Omar in 2008. Between 2007 and 2009 (Fig. 1a,c), approximately half (52%) of the live tissue cover was lost and colony size (average dimension) declined by 33%. No significant change was observed in colony abundance between 2007 and 2009 (Fig. 1b). The most notable change occurred in one study plot (SM3) where all colonies were reduced to fragments scattered outside of the plot and found dead in 2009. No substantial change was observed in any of these metrics between 2009 and 2010 (Fig. 1) among the Curaçao study sites.

Similar trends were observed at monitored sites in the upper Florida Keys following hurricane damage in 2005 (Fig. 1) where 50% of live *A. palmata* tissue (LAI) was lost with no change in average colony abundance between 2004 and 2006. Colony size declined by 24% in Florida Keys plots, following the 2005 hurricane season and has gradually increased (not significant) since then. Between 2006 and 2007 an increasing trend (non-significant, +8%) was observed in LAI and a decreasing trend (non-significant, -9%) in colony abundance. Overall, the magnitude of changes and general trends are strikingly similar between the two regions when compared relative to the year of hurricane disturbance (Fig 2, year 0 corresponding to 2008 in Curacao and 2005 in the Florida Keys).

White disease, snails and damselfish were included in the surveys as potential factors in population decline. Of these conditions, white disease (Fig. 3) is the most prevalent among monitored sites in Curaçao with an average prevalence over the four surveys of 29 ± 5.3% (mean ± SE) of colonies affected, followed by damselfish occupied colonies (12 ± 3.1%, mean ± SD; Fig.4) and snail-occupied colonies (11 ± 4.2%, mean ± SD; Fig. 4). Average white disease prevalence in Florida Keys surveys conducted during the same season as Curaçao surveys was substantially lower (ranged from 3 to 14%) than that of values from Curacao (19 to 42%) (Fig. 3). The proportion of colonies with disease signs consistent with WBD is 10 ± 5.7% in Curaçao and 2 ± 1.6% (mean ± SD; Fig. 5) in the Florida Keys.

Though more colonies are occupied by damselfish than snails, it is likely that snails have a greater impact on the recovery of *A. palmata* as a result of their high rate of live tissue consumption (Miller 2001) and potential disease transmission (Williams and Miller 2005). In the Florida Keys study plots, more colonies were occupied by snails (32 ± 4.9%, mean ± SD) and damselfish (38 ± 8.5%, mean ± SD) than in Curacao (Fig. 4). The average number of snails per snail-occupied colony is 4.6 snails per colony in both places, however they are more variable (clumped) in Curaçao (SD = 3.8) than in the Florida Keys (SD = 2.9).

Genotypic diversity (ratio of the number of genets to the number of colonies sampled or Ng/N) of *A. palmata* populations in Curaçao study plots is three times (0.67 ± 0.26, mean ± SD) greater than study plots in the upper Florida Keys (0.22 ± 0.11, mean ± SD) (Fig. 6), a pattern consistent with that described by Baums et al. (2006) for *A. palmata* at different sites in each region. These data may provide a useful tool in understanding the resilience and ability of these ecosystems to recover from future disturbances.

Synthesis

Acropora palmata populations in both locations experienced substantial losses of similar magnitude (~50% of live tissue) associated with hurricane damage. The Florida Keys population has been slow to recover even after 5 years. It would be premature to state whether or not Curaçao will recover faster than the Florida Keys populations. However, it is notable that in Curaçao the colony abundance increased the year after the storm (reflecting primarily recruitment of fragments) in contrast to Florida which has shown continued gradual decline in colony number and negligible recruitment of any sort (Williams et al. 2008). Our method of mapping to identify new recruits is greatly challenged by the volume of new fragments which makes it difficult to quantify recruitment of new colonies. The fact that quantifying recruitment is more tractable in the Florida Keys than Curaçao suggests that it is occurring at greater rates in Curaçao than the Florida Keys. In both regions, the total mortality of all colonies in a single plot occurred, with the remaining plots at those sites (Boca Santa Martha in Curaçao and Key Largo Dry Rocks in Florida) suffered dramatic declines in LAI as well.

The contrast in disease prevalence in the two regions is notable and somewhat paradoxical because it is substantially higher in the supposedly more robust Curaçao population. Although disease prevalence was lower in Florida Keys study plots, the comparison was only made between the spring surveys when disease prevalence happens to be at its annual low in the Florida Keys (unpubl. data). It is possible that disease is less seasonal or that the seasonal peak occurs in the spring in Curaçao whereas it occurs in fall in the Florida Keys. If the annual peaks in Florida are compared to the spring average for Curaçao, prevalence is equal for both Florida Keys sites (29% ± 14%, mean ± SD) and Curaçao sites (29% ± 11%, mean ± SD). In a similar study in the USVI from 2003-2009, intermediate disease prevalences have been observed in the April to May timeframe as compared to early summer and winter when disease is least prevalent and late summer/fall when it peaks (E Muller & C Rogers pers comm). The potential of differing seasonality in disease prevalence between the two regions also calls into question the exact nature and similarity of disease conditions being observed in each region. The current state of knowledge on coral diseases and the associated lack of authoritative field diagnostic tools preclude a solid answer to this fundamental question. Additionally, over seven year span of our Florida Keys monitoring, disease prevalence was unusually low throughout 2007 & 2008 suggesting that disease dynamics may display longer temporal cycles than has been captured in the 4 years of Curaçao surveys.

Prevalence of snail-occupied colonies is relatively low in Curaçao compared to the Florida Keys but similar to that reported from other Caribbean *A. palmata* populations (Bruckner et al. 1997; Bruckner 2000; Baums et al. 2003; Grober-Dunsmore et al. 2006; Zubillaga et al. 2008). Although the prevalence is approximately 3 times higher in Florida, it can be reasoned that their impact could actually be even greater. By extrapolating the number of snails per live tissue area (LAI), there are 0.8 to 1.8 snails per m^2 of live tissue (LAI) in Curaçao compared to 4.3 to 8.2 snails per m^2 LAI in the Florida Keys *A. palmata*. This greater snail 'load' is likely a more meaningful depiction of the difference in the impact of snail feeding on the Florida Keys *A. palmata* populations.

This study is not designed to assess population densities or spatial extent of *A. palmata*, so it is not possible to say quantitatively whether population density is greater in one location vs. the other.

However anecdotally, it is worth noting that when *A. palmata* was encountered in Curaçao it was more likely at colony densities that were too great to be amenable to the methods outlined in the Williams et al. (2006) protocol, whereas in the upper Florida Keys, it is more common to find the densities to be too low for the protocol methods. At minimum, this suggests that populations in Curaçao are more clumped than in the Florida Keys, which has implications for both sexual and asexual reproduction/propagation. Differences in the physiography of the two areas may account for some of the differences, as *A. palmata* is confined to a narrow swath around the island (Curacao) whereas back reef and fore reef spur and groove areas (typical of the remnant Florida Keys populations) may result in more scattered individuals.

Whether natural or the result of population decline, the implications of lower colony density are the same. Higher density stands in high energy areas may retain more fragments (Baums et al. 2003) than colonies scattered at lower densities. Successful fertilization requires gametes in great enough concentrations from unique genotypes to meet within a few hours of bundle release so fertilization success is likely greater at higher densities of genotypically diverse colonies. In Curaçao *A. palmata* prior to the 2008 hurricane, the greater density of larger more live colonies had a much greater chance of producing sexual recruits than did the lower genotypic diversity and colony densities of the Florida Keys populations. Furthermore, the impact of predation from corallivores may be distributed across more colonies in Curaçao, resulting in greater chances for individual survival, compared to isolated colonies in the Florida Keys, where predation may be focused until the colony is completely dead. All of these mechanisms suggest that above some critical density threshold populations may be reasonably self-sustaining in the face of disturbances. However, populations that have fallen below this threshold may experience accelerating declines leading to ever more scattered (sparse) populations up to local or regional extirpation.

In sum, Curaçao *A. palmata* populations suffered similar hurricane associated losses in 2008 as the Florida Keys populations did in 2005. It is too soon to say whether the Curaçao population will manifest hypothesized greater resilience by recovering faster from disturbances than the Florida Keys populations have, but this should be clearer in the coming years of the study. Disease prevalence suggests Curaçao populations may be more at risk; however fundamental uncertainties as to the nature of the disease conditions remain. The lower densities of snail predators in Curacao may help balance the impact of greater disease prevalence. Furthermore, the 2010 survey suggested that greater recruitment rates may foster faster recovery in Curaçao compared to the Florida Keys.

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Table 1. Location and colony abundance of 150m² area study plots. Number of colonies reflects total number of colonies in the study plot at the first survey (2006 in Curacao, 2004 in Florida).

Location	Site	Plot	Latitude	Longitude	# colonies
CURAÇAO	Blue Baai	BB1	12.13511	-68.98682	12
		BB2	12.13527	-68.9871	14
		BB3	12.1352	-68.98738	10
	Boca Santa Marta	SM1	12.2679	-69.12822	16
		SM2	12.2679	-69.12822	6
		SM3	12.26683	-69.1272	15
	Sea Aquarium Reef	SQ1	12.08417	-68.89493	53
		SQ2	12.08365	-68.89467	42
		SQ3	12.08312	-68.89585	31
UPPER FLORIDA KEYS	Carysfort	CF1	25.22194	-80.21055	17
		CF2	25.22178	-80.2106	37
		CF3	25.2229	-80.20956	11
	Elbow	EL1	25.14259	-80.25835	43
		EL2	25.1429	-80.25822	25
		EL3	25.14394	-80.2578	31
		EL4	25.14508	-80.25734	21
		EL5	25.14518	-80.2574	13
	French	FR1	25.03393	-80.34959	28
	Key Largo Dry Rocks	KL1	25.1236	-80.29736	17
		KL2	25.1229	-80.29787	27
		KL3	25.12255	-80.29826	15
	Molasses	ML1	25.00958	-80.37481	11
		ML2	25.00912	-80.37473	23
		ML3	25.01015	-80.37328	22

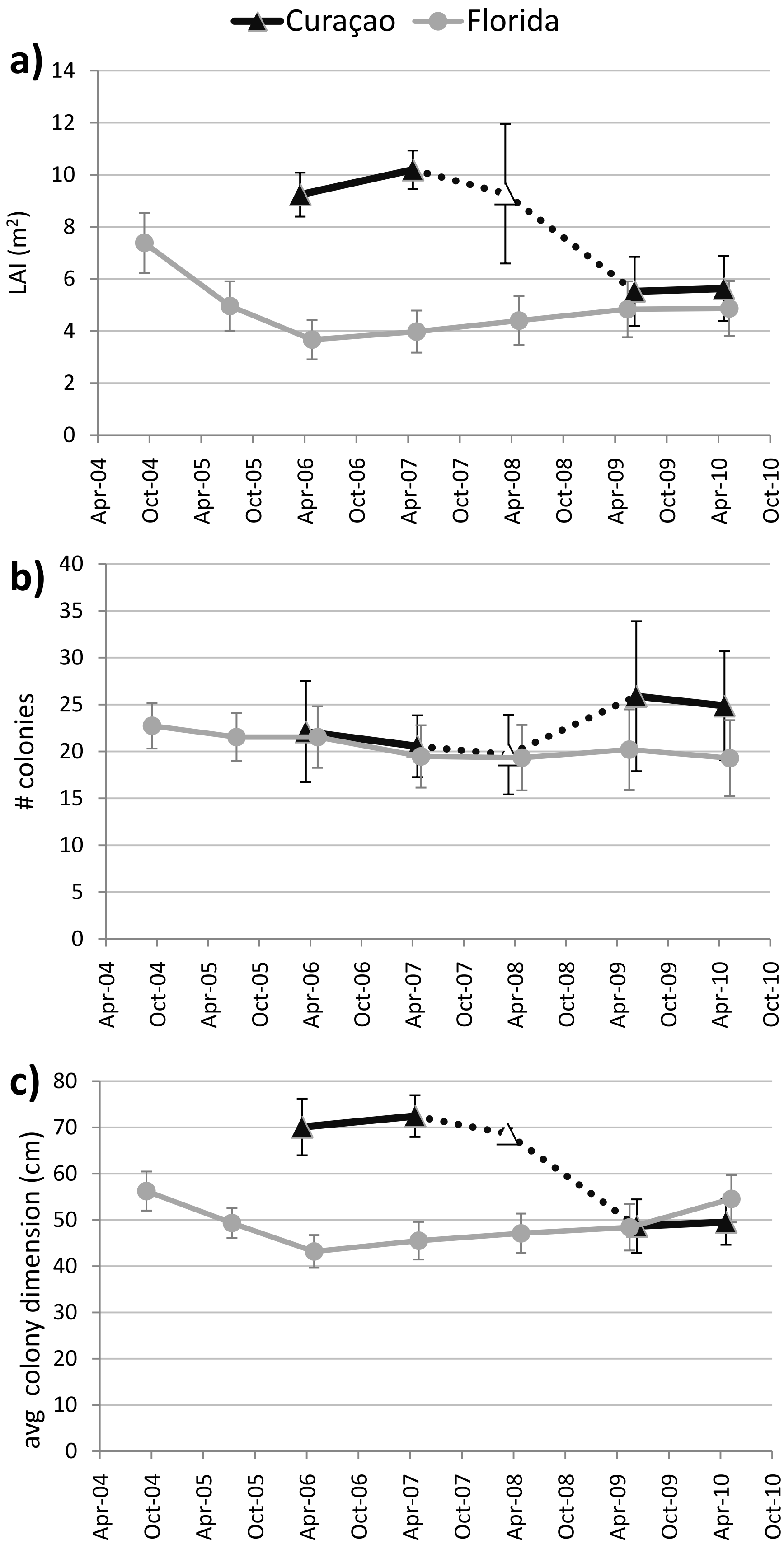

Figure 1. a) The average Live Area Index (LAI), b) average number of colonies and c) average dimension of colonies for plots in Curacao and the upper Florida Keys since the start of the study in each location. Hurricane impact occurred in 2005 for the Florida Keys and following the 2008 survey for Curacao. Error bars represent standard error. Dashed lines connecting to the 2008 Curaçao survey indicate fewer plots (n=3) were mapped in 2008 (compared to n=9 for the other years) .

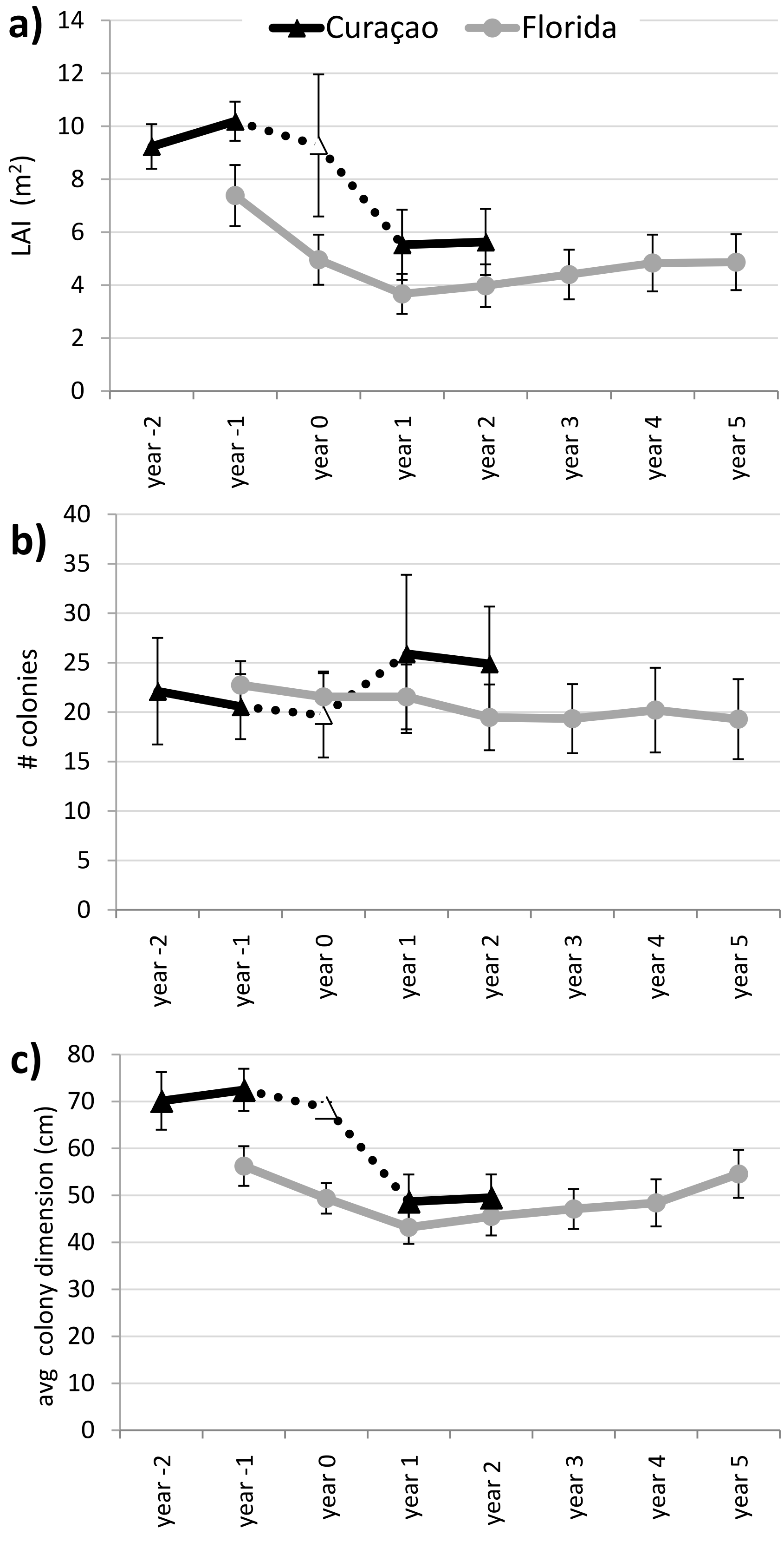

Figure 2. Same data as Fig 1 with temporal shift to compare trajectories relative to hurricane impact (year 0) in each region. a) The average Live Area Index (LAI), b) average number of colonies and c) average dimension of colonies for plots in Curacao and the upper Florida Keys Year 0 is 2005 for Florida and 2008 for Curaçao. Error bars represent standard error. Dashed lines connecting to the 2008 Curaçao survey indicate fewer plots (n=3) were mapped in 2008 (compared to n=9 for the other years) .

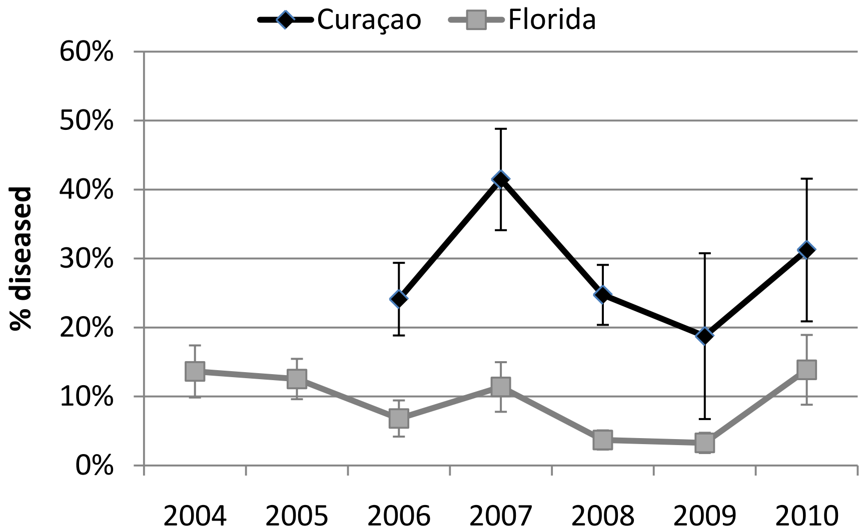

Figure 3. Average prevalence of white disease among tagged colonies during spring surveys in Curaçao and the upper Florida Keys. Error bars represent standard error.

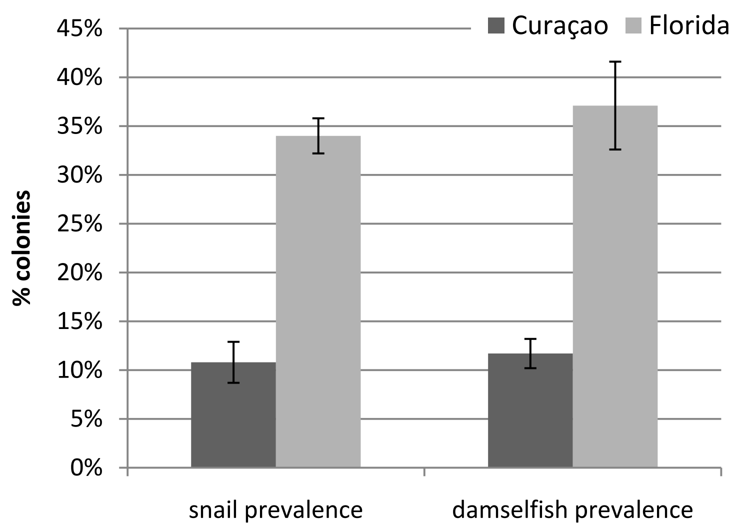

Figure 4. Average prevalence of colonies (over all plots and years) occupied by the three spot damselfish, *Stegastes planifrons*, and the gastropod, *Coralliophila abbreviata*, at sites in Curaçao and the upper Florida Keys. Error bars represent standard error.

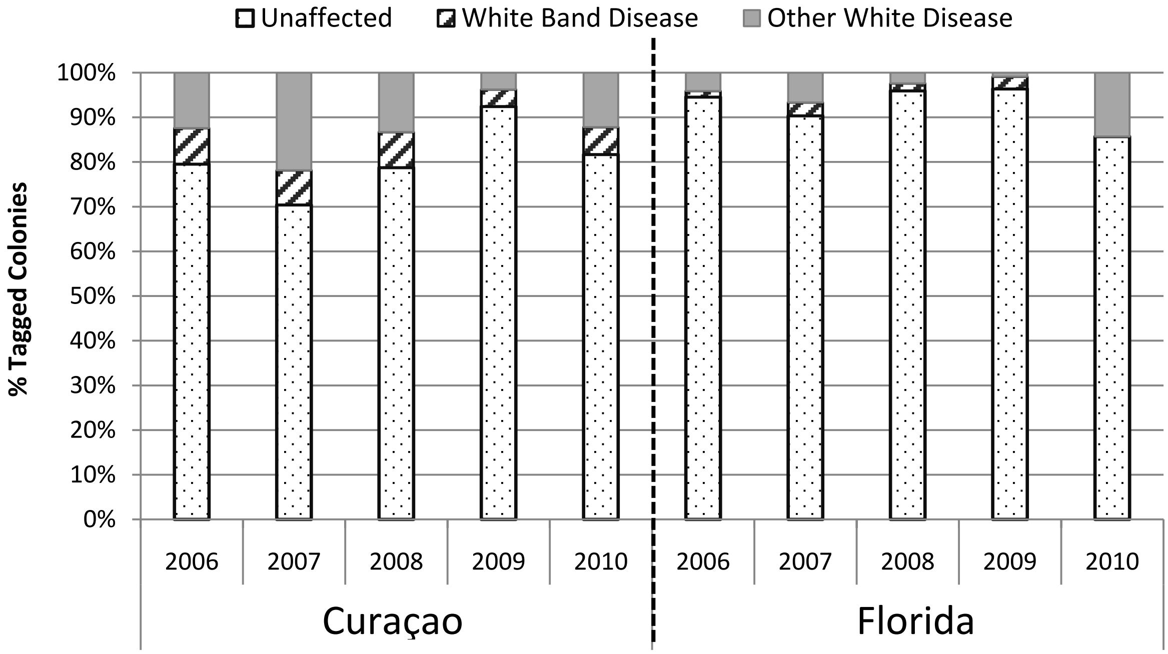

Figure 5. Disease condition of tagged colonies in Curaçao and Florida Keys during the spring survey each year. Colonies are categorized as unaffected by a white disease, having white band disease, or having signs of other 'white disease' not consistent with WBD. This 'other' category includes colonies with lesions consistent with the published description of WPx as well as more ambiguous recent tissue loss.

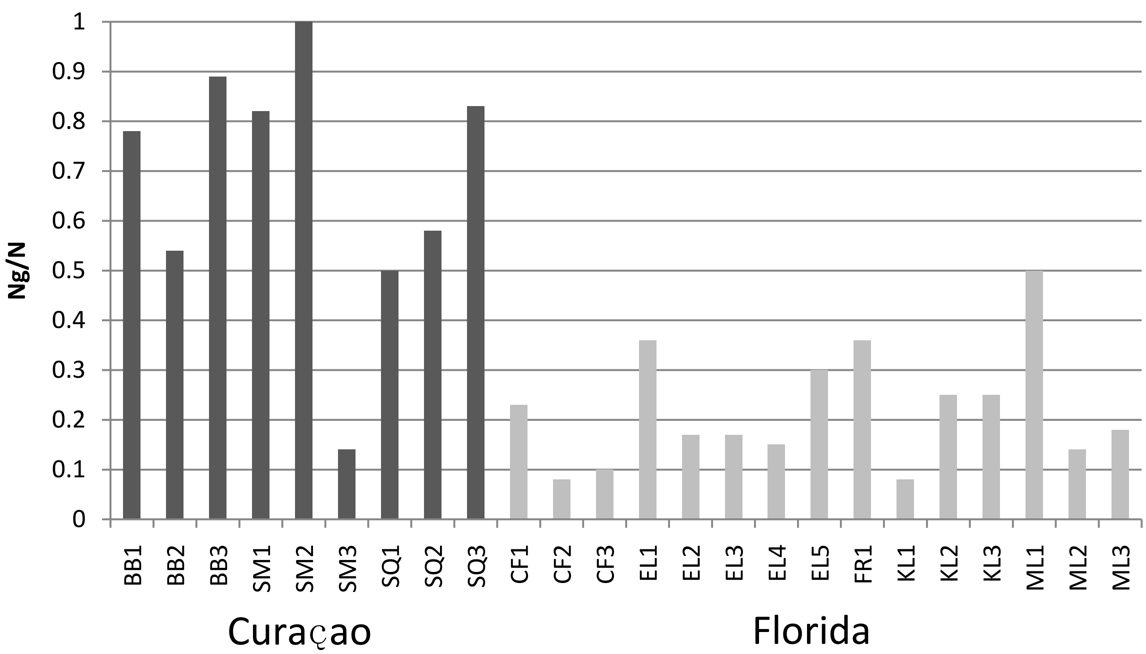

Figure 6. Genotypic diversity (Ng/N) of *Acropora palmata* at study plots in Curacao and the Florida Keys. Ng= Number of unique genets, N= number of sampled colonies.

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