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Massive hard coral loss after a severe bleaching event in 2010 at Los Roques, Venezuela

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Abstract: Thermal anomalies have become more severe, frequent and well-documented across the Caribbean for the past 30 years. This increase in temperature has caused coral bleaching resulting in reef decline. At Los Roques National Park, Venezuela, temperature has been monitored at four reef sites. In mid-September 2010, seawater temperature reached 30.85°C at 5 m depth in Los Roques, an archipelago only slightly affected by previous bleaching events. For example, bleaching in Los Roques in 2005 was mild compared to the rest of the Caribbean and to the results in this study. In 2010, seawater temperatures remained above 29.0°C from mid-August until the first week of November, resulting in +16 Degree Heating Weeks by that time. Our annual survey of four reef sites indicated that 72% of 563 scleractinian colonies were partial or totally bleached (white) or pale (discolored) in October 2010. In February 2011, there were still 46% of coral colonies affected; but most of them were pale and only 2% were bleached. By February, coral cover had declined 4 to 30% per transect, with a mean of 14.3%. Thus, mean coral cover dropped significantly from 45 to 31% cover (a 34% reduction). In addition to bleaching, corals showed a high prevalence (up to 16%) of black band disease in October 2010 and of white plague (11%) in February 2011. As a consequence, coral mortality is expected to be larger than reported here. Reef surveys since 2002 and personal observations for more than 20 years indicated that this bleaching event and its consequences in Los Roques have no precedent. Our results suggest that reef sites with no previous record of significant deterioration are more likely to become affected by thermal anomalies. However, this archipelago is relatively unaffected by local anthropogenic disturbance and has a high coral recruitment, which may contribute to its recovery. *Rev. Biol. Trop.* 60 (Suppl. 1): 29-37. Epub 2012 March 01.

Key words: coral bleaching, mortality, loss of coral cover, Caribbean, coral reefs.

Coral reefs are tropical ecosystems with high productivity and therefore they provide a myriad of ecological goods and services to human societies, particularly in developing countries (Moberg & Folke 1999). Coral reefs world-wide have shown signs of deterioration, mainly reported by the loss of coral cover. Hurricanes, bleaching, coral diseases, thermal anomalies and overfishing are among the factors that have been associated with coral reef

deterioration (e.g. Bellwood *et al.* 2004, Rogers 2009). In the Caribbean this phenomenon has been particularly evident, as extensive reductions of coral cover and the concomitant loss of architectural complexity have occurred (Gardner *et al.* 2003, Weil *et al.* 2006, Alvarez-Filip *et al.* 2009).

Mass bleaching events (MBE, events that reduce the density of *Symbiodinium* in its hosts over a large geographic area) have increased

in frequency and intensity (e.g. McWilliams *et al.* 2005); and it appears that they act synergistically with other detrimental factors to produce negative consequences for coral reef organisms, populations and communities (reviewed in Brown 1997). Thus, MBE have been reported across the Caribbean as a factor that reduces coral cover (e.g. Cortés 2003, Gardner *et al.* 2003). However, the effects and consequences of a particular bleaching event may vary between localities depending on oceanographic processes which is partly determined by reef morphology and topography; population size structure and species composition of coral communities (Brandt 2009). In 2005, prolonged thermal anomalies and its associated MBE occurred on a regional scale (e.g. Donner *et al.* 2007, Wilkinson & Souter 2008, Brandt & McManus 2009), but the largest coral cover losses related to this MBE were detected in the eastern Caribbean, where also epizootic events came after a prolonged bleaching period (Miller *et al.* 2006, Muller *et al.* 2008). In contrast, this bleaching event had mild effects in the southern Caribbean (Croquer & Weil 2009); particularly, in Venezuela (Rodríguez *et al.* 2010).

In 2010, another mass bleaching event was recorded worldwide (Normile 2010), although apparently not as severe as in 2005 for the Caribbean. However, coral reefs at Los Roques National Park (LRNP) were severely affected in 2010. Los Roques is a marine protected area characterized by healthy coral reef ecosystems compared to other sites in the Caribbean (Villamizar *et al.* 2003, Croquer *et al.* 2010; but see Croquer *et al.* 2005). The relatively good conditions of coral reefs ecosystems at LRNP (e.g. Schweizer *et al.* 2005) might be explained by low anthropogenic impacts, absence of runoff; and perhaps by the combination of low hurricane activity, low frequency of bleaching events, and thermal anomalies which seldom exceed few weeks over this geographic area. In this paper we provide the first evidence of a mass bleaching event producing significant impacts on coral reefs at Los Roques National Park.

MATERIAL AND METHODS

Study site: LRNP is located about 150 km north of the Venezuelan coast. This marine protected area encompasses 2211.4 km² of tropical marine ecosystems including mangroves, seagrass beds, soft-bottom communities, sandy and rocky shores and coral reefs. Reef development in Los Roques is extensive showing high diversity and live cover of scleractinian corals compared with other reef areas in Venezuela (Ramírez-Villarroel 2001) and other areas of the Caribbean (Rodríguez-Ramírez *et al.* 2008). Coral reefs at LRNP also differ within the region because of the presence of recovering populations of the threatened species *Acropora palmata* (Zubillaga *et al.* 2005) and *A. cervicornis*.

Seawater Temperatures: seawater temperatures were monitored with four HOBO data loggers (Pro-V2), at the four reef sites of the archipelago every 12 minutes. The loggers were fixed to the bottom near the coral, at an average depth of 5 m and the data shown here were from the 3rd of March 2010 to the 3rd of February 2011. The Degree Heating Weeks index (DHW) was calculated according to Liu *et al.* (2006). The estimation of monthly mean temperatures was done with a time series from May 2003 till July 2011 obtained from the MODIS-SCAR sensor (data obtained from <http://cariaco.ws/>).

Surveys of coral bleaching: In order to assess the magnitude of the 2010 MBE and its effects on coral reefs in LRNP, the proportion of bleached or pale colonies as well as the live coral cover was determined along ten, 10-m long, permanent transects located at each reef site, covering a depth interval of 5 to 15 m. This was carried out in October 2010, about one month after the onset of bleaching, and then again five months after the initial survey, in February 2011. During the initial survey, four reef sites (i.e. reefs located in the slope of different cays) were sampled: two located at the south-western edge of LRNP (Dos

Mosquises and Cayo de Agua) and two located in the north-east (Madrizquí and Rabusquí). The maximum distance among reef sites was 36 km, and their location and other characteristics have been described (Zubillaga *et al.* 2008, Croquer *et al.* 2010). Coral cover was estimated from chain transects (CARICOMP 2001), and the condition of coral colonies intercepted were also recorded (coloration, diseased, surface of partial mortality). In February of 2011, two sites were resurveyed (Cayo de Agua and Dos Mosquises Sur) to ascertain the effect of the bleaching event, six months after its onset. Therefore, comparisons between October 2010 and February 2011 were made only for these two sites, whereas results that pertain only to October 2010 were obtained from the observations at the four sites.

Statistical analysis: Null hypothesis of no temporal changes in live coral cover was compared with a repeated measures analysis of variances after checking ANOVA assumptions (i.e., normality and homogeneity of variances). Also a regression analysis was done to test whether the loss of live coral cover in each transect by February 2011 was linearly correlated with the proportion of colonies bleached in October 2010.

RESULTS

Seawater Temperature and Degree Heating Weeks: During 2010, the maximum temperature of 30.85 °C at 5 m depth was reached between the 17 and 19 of September at all four reef sites. At that depth, the seawater temperatures remained above 29.0 °C from mid-August until the first week of November 2010 (Fig. 1A). By that time, Degree Heating Weeks (DWH) reached a maximum value of 16 °C-weeks in the superficial waters of the archipelago (Fig. 1B, from NOAA) and 13 °C-weeks in waters at 5 m (data from in situ loggers).

Percentage of bleached and diseased coral colonies: In October 2010, 72% of the 563 scleractinian colonies were bleached or pale. In February 2011, there were still 46% of coral

colonies affected; but the recovery of zooxanthellae density was in place, as most of them were pale, and only 2% were bleached (Fig. 2).

The high prevalence of Black Band Disease (BBD) had no precedent since the beginning of our surveys in 2002. In fact, BBD has been only detected once before, in 2007, when it reached 1% in Dos Mosquises (DMS). In contrast, the prevalence of BBD was 6% in DMS and 16% in Cayo de Agua (AGU) in October 2010. By February 2011, we did not observe any sign of BBD in these localities.

In 2010, the prevalence of White Plague (WP, with no differentiation made between type I and II) was also high compared to previous years. Contrasting with the drop in prevalence of BBD, the prevalence of WP was higher in February 2011 (10 -11%) than in October 2010 (4 - 8%).

Analysis of the cover change: By October 2010, mean coral cover was 42.5% \pm 3.97 (\pm standard error) in AGU and 47.4% \pm 3.41 in DMS. By February 2011, it was 32.2% \pm 4.60 and 29.1 \pm 3.44, respectively. Thus, the coral cover dropped similarly between sites (repeated measures ANOVA Time*Reef $p > 0.05$; Fig. 3) and significantly from a mean of 44.9 to 30.6% (Time $p < 0.05$), with a concomitant loss of 17% in the number of colonies.

Although there could be other causes for the rapid loss of coral cover (including the onset of diseases), a great proportion is certainly attributable to the bleaching event of 2010. This assumption is based on the relatively short time period elapsed between the high seawater temperature anomaly and both surveys. Also, the proportion of bleached or pale colonies explained about 22% of the variability obtained in the net loss of coral cover in each transect ($r^2 = 0.2165$ for the regression shown in Fig. 4).

DISCUSSION

Considering the combined global land and ocean surface temperature, the year 2010 tied with 2005 as the warmest on record (NOAA 2010). Also, both are known as years where mass bleaching events (MBE) have occurred

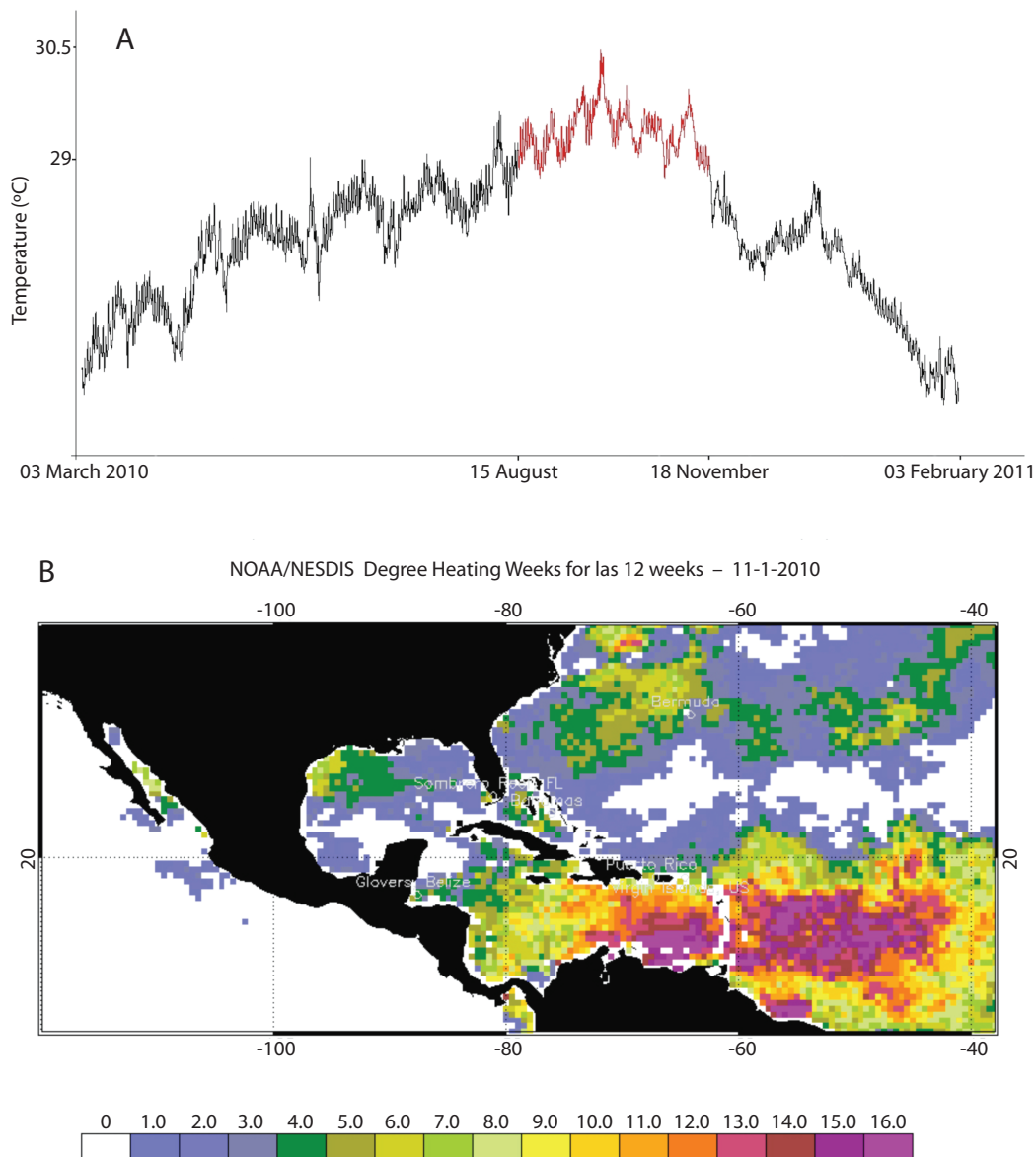


Fig. 1. A) Water temperature in °C at 5 m depth obtained *in situ* by a HOBO logger. Four reef sites were measured but only the data for Rabusquí is shown as it was very similar among sites. B) Degrees Heating Weeks (DHW) for the Caribbean region by November 1, 2010 (obtained from the NOAA, http://www.osdpd.noaa.gov/ml/ocean/cb/dhw_2010.html).

across the Caribbean. However, the intensity of the bleaching event and its consequences in Los Roques, Venezuela, were markedly different between these years. The bleaching event observed in October 2010 in Los Roques, and

the consequences recorded up to February 2011, had no precedent since we started our surveys in 2002 and have no match with our observations for more than 20 years in Venezuelan reefs. Thus, these coral reefs fall within

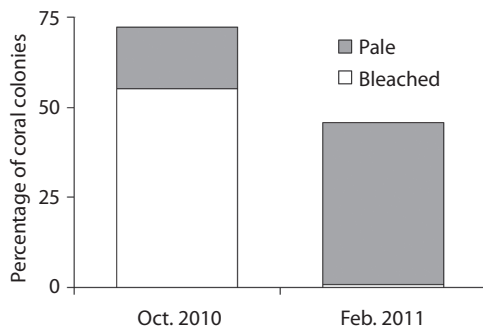


Fig. 2. Percentage of coral colonies that were bleached or pale in the sites surveyed in October 2010 (N= 563; four reef sites) and in February 2011 (N= 208; two reef sites) in Los Roques, Venezuela.

the expectations of a higher incidence and/or frequency of massive event of bleaching as temperatures rise above coral bleaching thresholds (Hoegh-Guldberg 1999).

Previous bleaching events observed in Venezuelan coral reefs have been mild compared with those that occurred during the same periods in other Caribbean localities (e.g. Lang

et al. 1992, Eakin *et al.* 2010). In Los Roques, in particular, less than 4% of coral colonies were bleached in August and September 2005 (Rodríguez *et al.* 2010), and <10% across the archipelago at the peak of the event in November 2005 (Villamizar *et al.* 2008). In contrast, the 2005 MBE was severe across the Caribbean, particularly in the eastern reefs, where percentage of bleached corals reached up to 80% (Ballantine *et al.* 2008, Oxenford *et al.* 2008, Brandt & McManus 2009, Croquer & Weil 2009, Miller *et al.* 2009, Eakin *et al.* 2010). A series of climatic and oceanic factors contribute to the variability in the thermal stress across the region (e.g. hurricanes, irradiance, water flow), which in turn results in spatial and temporal variations of the bleaching intensity (e.g. Jokiel & Brown 2004).

The distribution of heat in the superficial water masses along the Venezuelan coast was completely different between 2005 and 2010 (Fig. 1A in Eakin *et al.* 2010 versus Fig. 1B in this study) and this can be considered a factor contributing to the differences in bleaching intensity observed between 2005 and

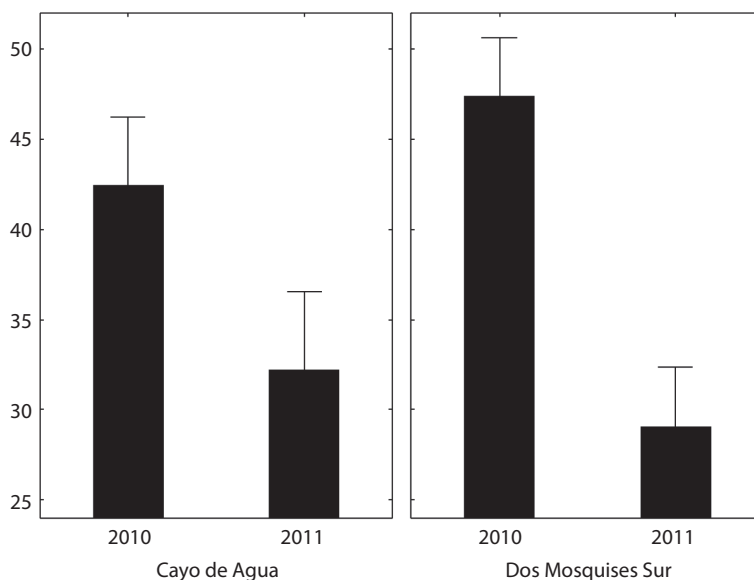


Fig. 3. Hard coral cover (%) measured in October 2010 and in February 2011 at two reef sites (Cayo de Agua and Dos Mosquises); Los Roques, Venezuela.

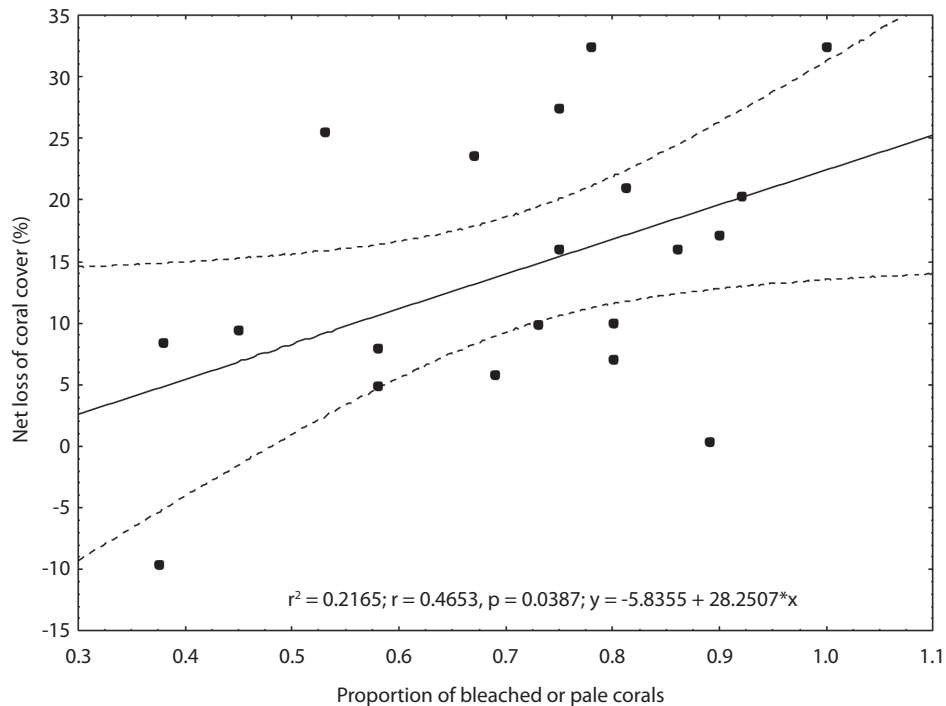


Fig. 4. Relationship between the net coral loss (%) that occurred between October 2010 and February 2011, and the proportion of colonies that were bleached or pale by October 2010 at two reef sites in Los Roques, Venezuela.

2010. It is well known that bleaching severity is determined by a combination of intensity and duration of thermal stress and irradiance conditions (Glynn & D'Croz 1990, Lesser & Farrell 2004). *In situ* measurements indicated that maximum temperatures in the archipelago (excluding the internal lagoon) were about 1°C higher in 2010 than in 2005 for the same period (29.92 °C in 2005 vs. 30.85 °C in 2010). Concomitantly, Degree Heating Weeks (DHW) calculated from *in situ* loggers did not exceed the value of 5 °C-weeks in 2005 (Villamizar *et al.* 2008) for the reefs surveyed in this study, whereas it reached 13 °C-weeks in 2010. It has been generalized that values of over 4°C-weeks cause significant bleaching, and values over 8°C-weeks cause widespread bleaching and some mortality (Liu *et al.* 2006), which was also the case in this study.

Another example of the variability in bleaching intensity is illustrated by the

differences found between the 2005 and 2010 MBE in Venezuela. In 2005, bleaching intensity was higher in coastal rather than oceanic reefs (16% vs. <4% of bleached corals, Rodríguez *et al.* 2010). The opposite trend was found in 2010, when intensity seemed higher for the oceanic reefs of Los Roques compared to coastal reefs of Morrocoy (personal observations). These results contrasted with other studies that have consistently found more severe MBE in inshore waters compared to outer reefs (e.g. Berkelmans *et al.* 2004).

Coral cover was severely reduced (by 36%) at our study sites in Los Roques after the 2010 bleaching event, which was similar to the 40% mortality observed in 2005 across the Caribbean (Eakin *et al.* 2010). However, we suspect that the long-term consequences could be worse in Los Roques, because during our last survey (February 2011): a) the bleaching was still ongoing as 46% of colonies remained

pale, despite a drop in seawater temperature; and b) there was a high prevalence of white plague (~10%) by that time. Previous studies indicate that after a MBE, the mortality of corals can span for about two years (e.g. Eakin *et al.* 2010), as well as its detrimental consequences on coral reproduction (e.g. Szmant & Gassman 1990). Also, the onset of diseases associated to the MBE, particularly black band disease, white plague and yellow band disease, can contribute further to the loss of coral cover (e.g. Brandt & McManus 2009, Miller *et al.* 2009, Weil *et al.* 2009).

The loss of coral cover induced by the 2010 MBE in Los Roques has no precedent at least in 20 years. Although we expect that MBE-induced coral mortality to continue for several months after our last survey, a rapid recovery in Los Roques could be possible because a relatively high coral cover (~30%) is still present in many reefs of the archipelago, there is relative low anthropogenic impact (e.g. a permanent population of ~ 2,000 inhabitants), and high coral recruitment rates have been found (Humanes 2009). Venezuelan coastal reefs, that lack these conditions, have shown very slow recovery after massive mortality events (Bastidas *et al.* 2006). Unfortunately, the positive expectations for the recovery of reefs in Los Roques depend on other large scale factors that are difficult to foresee, such as the distribution of thermal anomalies across the Caribbean.

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RESUMEN

Durante las últimas décadas las anomalías térmicas han sido más frecuentes y severas en el Caribe, quedando pocos arrecifes exentos de eventos masivos de blanqueamiento (EMB). En el Parque Nacional Los Roques, Venezuela, un archipiélago poco afectado previamente por EMB, la temperatura del agua a 5m de profundidad alcanzó 30,85°C en septiembre 2010, y fue >29,0°C entre mediados de agosto y la primera semana de noviembre en cuatro arrecifes. El 72% de 563 colonias de escleractinios estaban blanqueadas o pálidas para octubre de 2010, mientras que para febrero 2011, el 46% de las colonias aún estaban afectadas. Para febrero 2011, la cobertura béntica coralina promedio disminuyó de 45 a 31%. Además, los arrecifes mostraron una alta prevalencia (de hasta 16%) de enfermedad de banda negra en Octubre 2010, y de plaga blanca (11%) en Febrero 2011. Como consecuencia, es probable que la mortalidad coralina resulte mayor a la reportada acá. Sin embargo, Los Roques es poco afectado por perturbaciones antropogénicas y cuenta con un alto reclutamiento de corales, lo cual podría contribuir a su recuperación.

Palabras clave: blanqueamiento coralino, mortalidad, pérdida de cobertura de coral, Caribe, arrecife coralino.

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