Severity of the 1998 and 2005 bleaching events in Venezuela, southern Caribbean

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Abstract: This study describes the severity of the 2005 bleaching event at 15 reef sites across Venezuela and compares the 1998 and 2005 bleaching events at one of them. During August and September 2005, bleached corals were first observed on oceanic reefs rather than coastal reefs, affecting 1 to 4% of coral colonies in the community (3 reef sites, n=736 colonies). At that time, however, no bleached corals were recorded along the eastern coast of Venezuela, an area of seasonal upwelling (3 reefs, n=181 colonies). On coastal reefs, bleaching started in October but highest levels were reached in November 2005 and January 2006, when 16% of corals were affected among a wide range of taxa (e.g. scleractinians, octocorals, *Millepora* and zoanthids). In the *Acropora* habitats of Los Roques (an oceanic reef), no bleached was recorded in 2005 (four sites, n=643 colonies). At Cayo Sombrero, a coastal reef site, bleaching was less severe in 1998 than in 2005 (9% of the coral colonies involving 2 species vs. 26% involving 23 species, respectively). Our results indicate that bleaching was more severe in 2005 than in 1998 on Venezuelan reefs; however, no mass mortality was observed in either of these two events. Rev. Biol. Trop. 58 (Suppl. 3): 189-196. Epub 2010 October 01.

Key words: coral reefs, stress, global warming, bleaching.

During the past three decades, coral reefs have suffered significant impacts worldwide (Bellwood *et al*. 2004). Among many stressors, massive coral bleaching events (MCBEs), defined as regional reductions of coral cover of 40 to 100%, have become an important factor in reef decline on a global basis (Hoegh-Guldberg 1999). For over 25 years, MCBEs have been frequently reported world-wide: in the Indo-Pacific (Brown & Odgen 1992, Hoegh-Guldberg 1999, Hoegh-Guldberg & Salvat 1995, Woesik *et al*. 2004), Red Sea (Fine & Loya 2004), Eastern Pacific (Glynn 1993, Glynn *et al*. 2001, Guzman & Cortés 1992, 2001), Indian Ocean (McClanahan 2004) and the Caribbean (Lang *et al*. 1990, Gardner *et al*. 2003).

The 1990s were perhaps the worst decade for coral reefs, with at least three (1990, 1995 and 1998) destructive MCBEs being recorded along the Great Barrier Reef (Berkelmans & Olivares 1999, Baird & Marshall 1998) and in the Andaman Sea, Thailand, French Polynesia and the Caribbean (Lang 1990, Brown 1997, Aronson *et al*. 2002). After the 1998 MCBE, only background bleaching (i.e. very few colonies showing bleaching signs) was reported. In 2005, however, a new MCBE was recorded affecting corals and other sessile organisms in the Caribbean. Early reports started in the Caribbean during August 2005 and continued throughout January-March 2006 in other bioregions (see the coral list).

Coral bleaching occurs when physiological thresholds are exceeded, disrupting the coral-zooxanthellae association. While prolonged and intense sea surface temperature anomalies (SSTA) have been correlated with massive bleaching events (Buddemeier & Fautin 1993, Brown 1997, Hoegh-Guldberg 1999), other stressors such as a high incidence of UV, changes in salinity, etc., also trigger the expulsion of zooxanthellae from their hosts (Douglas 2003, Glynn & D'Croz 1990), the loss of zooxanthellar photosynthetic pigments and/or structural damages due to oxidative stress (Lesser 1997, 2004). In 2005, a prolonged and intense SSTA occurred across the Caribbean for over six months resulting in extensive bleaching across the region.

Despite the 2005 MCBE being considered the most intense ever recorded in the Caribbean, assessments of its temporal and spatial variability and its magnitude are scarce and/or anecdotal. In this study, we assessed the severity (i.e. percentage of corals and other reef organisms pale or bleached) and the intensity (i.e. percentage of surface area pale or bleached in a colony) of bleaching at 15 reef sites located across the Venezuelan coast, at oceanic islands and in upwelling zones. In Cayo Sombrero, we also monitored bleaching for 18 months and compared the severity of the 1998 and 2005 MCBEs.

MATERIALS AND METHODS

In order to assess the spatial variability of the 2005 MBCE, the percentage of bleached organisms on reefs was estimated at 15 sites located at four localities (Fig. 1): two oceanic (Los Roques National Park [LRNP] and La Blanquilla [LB]) and two coastal (Mochima and Morrocoy National Parks). At each locality, the percentage of corals, octocorals and zoanthids (185-715 colonies per locality) showing signs of bleaching (i.e. partial or total loss of color) was quantified. We also estimated the intensity of the bleaching event by quantifying the relative percent of the surface affected by bleaching in each colony. For this, five qualitative categories were used in the field: 1-10%, 11-25%, 26-50%, 51-75% and >75% of the colony area affected. Sites were assessed during opportunistic expeditions, thus the sites differ in the methods used and the number of replicates (Table 1). Eleven out of the 15 surveys were done by determining the bleaching status of each coral colony (or any other zooxanthellate benthic organism) encountered below a 10m chain transect. Three of the surveys were done by annotating the bleaching status of coral colonies encountered in a free swimming period of 35 minutes; and in one survey this was done using a belt transect of 2x10m (Table 1). Since surveys

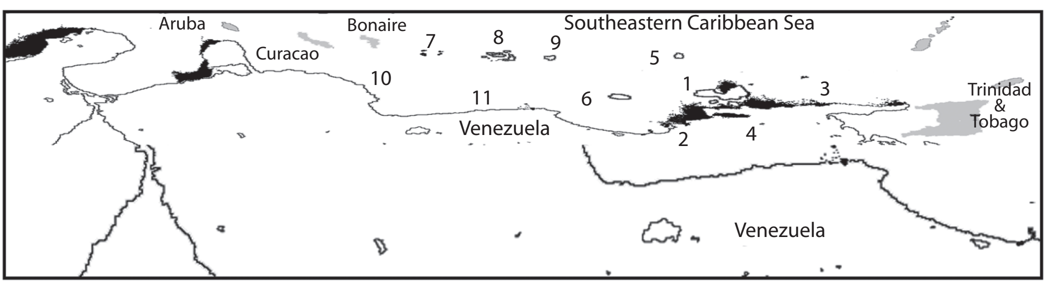

Fig. 1. Coral areas (marked with numbers) and main upwelling areas (marked in black) of Venezuela. Average SST (obtained from MODIS sensor at http://cariaco.ws/) in upwelling areas was <24.7°C during the first trimester of 2006. Coral areas under the influence of upwelling include Islas de Margarita, Coche, Cubagua and Los Frailes (1); Parque Nacional Mochima (2); Los Testigos (3) and Golfo de Cariaco (4). Coral areas partially influenced by upwelling include La Blanquilla (5) and La Tortuga (6). Coral areas out of the upwelling influence include: Archipiélago de Aves (7), Archipiélago Los Roques (8), Isla La Orchila (9), Parque Nacional Morrocoy and Cuare (10); and various sites of the Central coast (11). The figure frame shows 8 to 16° N and 58 to 77° W.

TABLE 1

Sampling sites, their locality and region, sampling method, number of replicates and total number of colonies examined in the assessment of the 2005 Caribbean MCBE (PNMy: Parque Nacional Morrocoy, PNMa: Parque Nacional Mochima, PNALR: Parque Nacional Archipielago de los Roques, LB: Isla La Blanquilla)

	Localities	Sites	Sampling method	Replicates	Colonies
Continental	PNMy	Cayo Norte	10m transects	10	138
		Cayo Sombrero 1, Sep		10	160
		Playa Caiman		10	54
		Cayo Sombrero 1, Oct		5	99
		Cayo Sombrero 1, Dec		5	97
		Cayo Sombrero 2		5	108
		Playa Mero		5	145
		Cayo Suanchez		5	101
		Cayo Pescadores		5	158
	PNMa	Punta La Virgen	35min visual surveys	1	76
		Playa Blanca Norte		1	45
		Playa Blanca Sur		1	60
Oceanic	PNALR	Dos Mosquises Sur	10m transects	10	146
		Madrisqui		10	129
	LB	Tres Playas	2x10m belt transects	8	461
			Total	91	1977

were conducted during different months at different reef sites, results were grouped into the following periods: (1) August-September 2005, (2) November-December 2005 and (3) January-February 2006.

Temporal changes in bleaching severity and a comparison of the 2005 and 1998 MCBEs were undertaken on the reef at Cayo Sombrero (BCS) because it has been monitored every six months since 1996 as part of the CARICOMP program. In order to evaluate the temporal changes of coral bleaching and its effects on the coral community at this site, we quantified the severity of bleaching and the coral cover every six months, starting at the onset of the 2005 bleaching event and up to 18 months thereafter, a period that involved four surveys. Both, the prevalence of bleaching and coral cover were estimated in ten 10m permanent transects.

RESULTS

Severity and intensity of coral bleaching in 2005: In Venezuela, the 2005 MCBE first affected oceanic reefs during August and September 2005, bleaching 1 to 4% of the corals at LRNP (2 reef sites, n=275) and LB (1 reef site, n=461), the bleached surface of scleractinian corals seldom exceeding 10% (Fig. 2). During this period, however, no bleaching was recorded on any of the coastal reefs (3 sites, n=512). The 2005 MCBE did not affected the northern-eastern coast of Venezuela (3 sites, n=181), a region seasonally subjected to upwelling.

Coastal coral reefs off Morrocoy on the western coast of Venezuela started to bleach in November-December 2005 and affected 14% of the colonies (6 reef sites, n=911). Here, bleaching intensity also increased within this

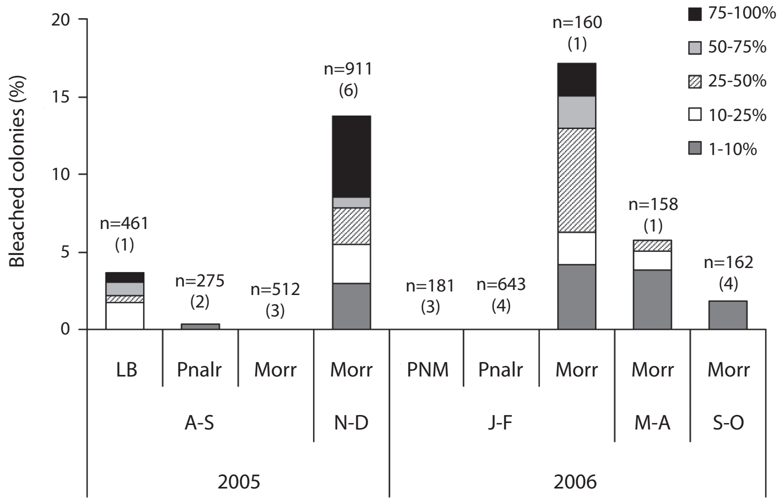

Fig. 2. Bleached colonies (% colonies) at four reef zones in Venezuela (A-S: August September; N-D: November-December; J-F: January-February; M-A: March-April; S-O: September-October. N=number of observed coral colonies. Reef sites at each zone in parentheses. The patterns in the bars refer to the surface of the colonies that was bleached, as per legend. Oceanic zones: Isla de La Blanquilla (LB) and Parque Nacional Archipiélago de los Roques (Pnalr); coastal zones: Parque Nacional Morrocoy and Refugio de Fauna Silvestre de Cuare (Morr) in the western, and Parque Nacional Mochima (PNM) in the eastern, upwelling coast.

period, with more than 5% of corals manifesting >75% of surface bleaching (Fig. 2).

By the end of January-February 2006, the bleaching at Morrocoy had extended to 14-17% of the colonies but the percentage of corals severely bleached was reduced from 5 to 2% (Fig. 2). At this time, colonies of *Acropora palmata* were not bleached at either of the two sites at LRNP; however, 1-10% of the colonies of *Montastraea faveolata* were bleached in deeper areas of these reefs (n=643).

By March-April 2006, less than 6% of the corals at Morrocoy were bleached and in 3% of them (n=158), bleaching was not intense and only 1-10% of the total colony area was affected. Bleaching severity steadily decreased from April to October 2006, with less than 2% of the colonies (n=162) showing bleaching by the end of this period (Fig. 2).

During the onset of the 2005 MCBE, populations of many sessile benthic organisms were affected at all sites. Scleractinian corals such as *Montastraea* (48%, n=202), *Agaricia agaricites* (16%, n=82), *Colpophyllia natans* (14%, n=43) and hydrocorals of the genus *Millepora* (7%, n=70) were affected in particular. Encrusting and erect octocorals and zoanthids were also severely affected in 2005, with 65% (n=65), 5% (n=55) and 85% (n=46) of the colonies bleached, respectively.

In terms of temporal variation, the 2005 MCBE started in October at Cayo Sombrero (22%, n=99), reached its peak in November (31%, n=97) and decreased steadily during the next four months (January: 18%, February: 10% and March 2006: 6%). The intensity of bleaching was similarly reduced between December 2005 and March 2006 as only 2% of the colonies remained bleached in March and more than 50% of their area was bleached or pale (Fig. 3).

Comparison of the 1998 and 2005 MCBEs: The reef site at Sombrero was affected by MCBE in 1998 and 2005. In both cases, the peak of bleaching occurred during the last

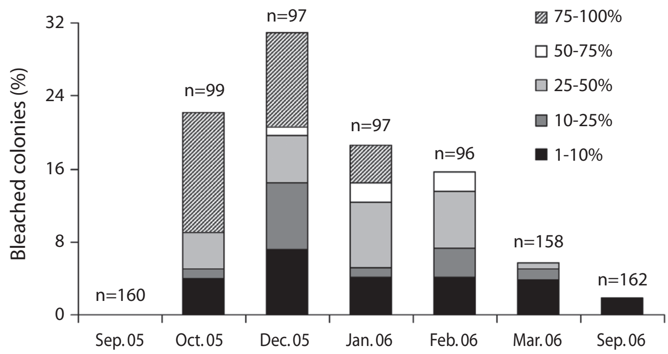

Fig. 3. Bleached colonies (% colonies) at Cayo Sombrero from September 2005 until September 2006. N=number of colonies examined. The patterns in the bars refer to the surface of the colonies that was bleached, as per legend.

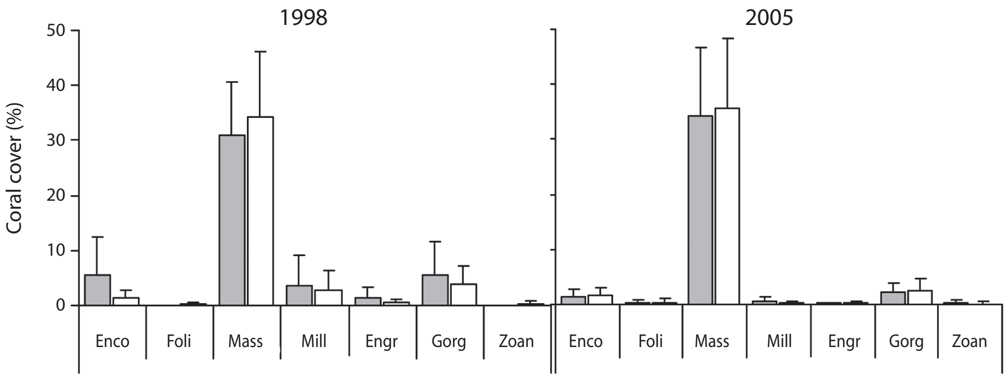

Fig. 4. Living cover of benthic taxa at Bajo Cayo Sombrero before (grey bars) and after (white bars) bleaching in 1998 and 2005. Enco: encrusting corals, Foli: foliose corals, Mass: massive corals, Mill: *Millepora* spp, Engr: encrusting octocorals, Gorg: branching octocorals, Zoan: zoanthids.

trimester of each year. However, during 2005 the percentage of bleaching (26%, n=196) was three-fold higher than in 1998 (9.4%, n=160). Furthermore, during 1998, only two massive scleractinian genera were bleached: *Montastraea* (8.7%) and *Colpophyllia* (0.6%), whereas during 2005, seven species including massive, foliaceous and encrusting corals were bleached. Also, at least two species of octocorals and zoanthids were affected by bleaching in 2005. Few months after the peak of stress of both, the 1998 and 2005 MCBEs, bleached colonies recovered in Sombrero and no important changes in the community structure of this site were detectable (Fig. 4).

DISCUSSION

This study shows that the two largest, global MCBEs in 1998 and 2005 affected coral reefs in Venezuela, the former being less severe and affecting fewer taxa than the latter. The effects of these MCBEs on Venezuelan reefs were negligible compared to other sites in the Caribbean, probably because of their late onset

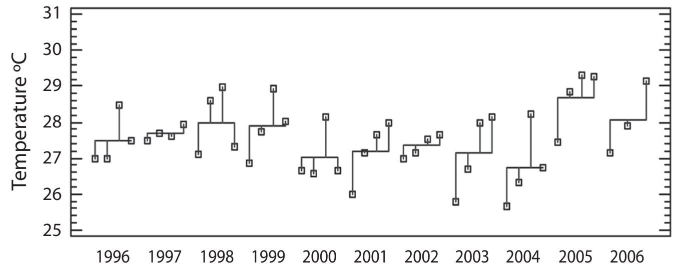

Fig. 5. Quarterly (□ symbols) and annual mean SSTs (horizontal lines) at Cayo Sombrero. Maximum annual means were attained in 1998 and 2005. SSTs were higher during the second trimester of these bleaching years, which did not occur in non-bleaching years.

and lower intensity and persistence in Venezuela. Neither the coral cover nor the prevalence of coral diseases (data not shown) changed at any of the five reef sites monitored by GCRMN and CARICOMP before and after the bleaching event of 2005 (Rodriguez-Ramirez *et al*. 2008). Nevertheless, we cannot disregard the possibility of future impacts in the coral community structure (e.g. reduction of coral cover, structural complexity and increase in disease) if MCBEs continue to increase in intensity, severity and frequency.

Either the length of exposure to, or the severity of, a given temperature stress or anomaly might result in coral bleaching (Glynn & D'Croz 1990). Bleaching has been observed either when corals are subjected to sharp (1-2°C) increases in SST over short periods (i.e. few days) or when temperature moderately increases (0.5°C) for longer periods of time (Glynn & D'Croz 1990). A comparative analysis of SSTA and the patterns of coral bleaching in the Caribbean in 2005 show that this event could have been caused by the combination of prolonged (>6 months) exposure to elevated sea water temperatures (an increase of 2-2.5°C above the mean). Likewise, the 1998 MCBE was correlated with intense and prolonged SSTA for that year.

Coral bleaching has been often linked to coral reef decline in Latin American and Caribbean coral reefs (Cortés 2004). While major bleaching events in the Caribbean have been recorded during ENSO years (1982-1983, 1988-1989), other bleaching events have been reported during SSTA not associated with ENSOs (1995, 1997, 1998-1999). Previous major bleaching events associated with ENSOs produced extensive bleaching and a subsequent significant reduction of coral cover (10-70%) across the Caribbean (e.g. Panama, Belize, Costa Rica, Colombia and Venezuela, among others) and affected a broad range of species, especially *Agaricia* spp., *Millepora* spp. and the *Montastraea* species complex (Lasker *et al*. 1984, Lang *et al*. 1992, Fitt *et al*. 1993, CARICOMP 1997b, Guzmán 2003, Gibson & Carter 2003, Cortés & Jiménez 2003, Garzón-Ferreira & Díaz 2003, Weil 2003).

In Venezuela at least two SSTAs were recorded at Sombrero during 1998 and 2005: (1) mean annual temperatures in 1998 and in 2005 were above those in previous years when bleaching was not recorded and (2), SSTs were higher during the second trimester of these bleaching years, which did not occur in non-bleaching years (Fig. 5). Furthermore, the thermal anomaly recorded in 2005 was more intense than the one of 1998 (Fig. 5), which explains why the bleaching event in 2005 was more severe than in 1998. Thus, our results support studies that have evidence for a causal relationship between ocean warming and bleaching, although other factors could be involved (see Introduction). As in 1995 and 1998, in Venezuela the peak of bleaching in

2005 was less intense and severe than in other areas in the Caribbean and lagged behind that elsewhere in the region (Wilkinson & Souter 2008). This result suggests that MCBEs in the southern Caribbean normally occur two-three months later (October-November) than in other areas in the region (July-August in 1998 and 2005). A lower intensity of thermal stress in the southern Caribbean might explain this pattern. For instance, in Venezuela, the maximum SST recorded in 1998 was 29.2ºC, whereas in the western and the northern Caribbean SST reached 29.7 and 30.2ºC, respectively (Sheppard & Rioja-Nieto 2005).

Corals derive more than 90% of their energy from zooxanthellae (Muscatine 1990). However, energy storage used to fulfill vital functions (e.g. reproduction, growth, defense mechanism, repair, etc.) is limited. Therefore, MCBEs may have deleterious effects on coral reef communities, causing massive mortalities, increases in susceptibility to opportunistic infections, and reductions in reproductive output (Baird & Marshall 1998, Aronson *et al*. 2002). In contrast to other localities in the Caribbean (Buddemeier & Fautin 1993), the 1998 and 2005 MCBEs did not result in significant changes in coral cover in Venezuela at the two oceanic and three coastal reef sites surveyed before and after these events. This result was consistent with trends in coral cover in Cayo Sombrero, Morrocoy, where coral cover has remained unchanged for over 12 years (CARICOMP, unpublished data). Likewise, the prevalence of coral diseases only increased at one out of the five sites surveyed after the 2005 bleaching event, which suggests that bleaching did not increase the incidence of disease in the corals.

In conclusion, the 2005 MCBE affected oceanic reefs of Venezuela two months before coastal reefs; however, bleaching was more intense and severe in the latter (west coast of Venezuela, Morrocoy). Coral reefs located on the east coast of Venezuela, which are normally subjected to upwelling (SST=23°C in January 2006), were not affected by the 2005 MCBE compared to non-upwelling areas (SST>27°C in January 2006). The MCBE in 2005 was more severe and intense than in 1998, affecting a wider range of marine organisms at higher intensity.

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RESUMEN

En este estudio se describe la severidad del evento de blanqueamiento del 2005 en 15 arrecifes coralinos de Venezuela, y se compara con el ocurrido en 1998 para uno de esos arrecifes. Los primeros corales blanqueados se observaron en agosto y septiembre 2005, en arrecifes oceánicos en lugar de costeros, afectando entre 1 y 4% de las colonias coralinas (3 arrecifes, n= 736 colonias). Para ese momento, tampoco se había detectado blanqueamiento en áreas oceánicas de la costa este de Venezuela (3 arrecifes, n= 181 colonias), donde ocurre una surgencia estacional. En arrecifes costeros, el blanqueamiento comenzó en octubre pero alcanzó su máximo entre noviembre 2005 y enero 2006, afectando hasta el 16% de los organismos de una variedad de taxa (e.g. escleractinios, octocorales, Millepora, zoántidos). En los hábitats de Acropora de Los Roques, no se observó blanqueamiento en el 2005 (4 sitios oceánicos, n= 643 colonias). En Cayo Sombrero, un arrecife costero, el blanqueamiento fue menos severo en 1998 comparado con el de 2005 (9% de colonias coralinas de 2 especies vs. 26% de colonias de 23 especies, respectivamente). Estos resultados indican que el blanqueamiento del 2005 fue más severo que el de 1998 en los arrecifes de Venezuela, sin embargo, no ocurrió mortalidad masiva asociada a ninguno de los dos eventos.

Palabras clave: blanqueamiento, arrecifes, cambios comunitarios, calentamiento global.

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