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9A Coral bleaching and climate change

Upwelling mitigates coral bleaching in the Colombian Caribbean

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Abstract. The first moderate coral bleaching event for decades in Tayrona National Natural Park (Colombian Caribbean) was observed between November and December 2010. The patchy local coral communities were also influenced by seasonal upwelling that decreased water temperatures from 28 °C to 21 °C from December 2010 until February 2011. This upwelling may mitigate coral bleaching. Patterns of coral bleaching were compared before and after upwelling at an upwelling-exposed and -sheltered site in Gayraca Bay. Findings revealed that bleaching was more pronounced at the sheltered sites with 34 % of all scleractinian corals being affected compared to only 8 % at the exposed site in December 2010. By April 2011, almost all previously bleached corals (97 %) at the upwelling-exposed site had recovered from bleaching. In contrast, only 77 % of bleached corals had recovered at the upwelling-sheltered site and 12 % had died. These results support the hypothesis that seasonal upwelling mitigates coral bleaching and facilitates recovery, however the causal environmental factors have not being identified so far. Continuous temperature monitoring in high temporal resolution did not reveal any significant differences between sites. Future research should therefore focus on the water current regime in order to assess potential key influences on coral reef functioning in Tayrona National Natural Park.

Key words: Coral bleaching, Upwelling, Colombian Caribbean, Coral resilience, Coral adaptation

Introduction

Scleractinian corals function as key ecosystem engineers on reefs by providing habitat for many other reef organisms and transforming inorganic and organic materials (reviewed in Wild et al., 2011). Colombian Caribbean coral reefs are experiencing similar threats to other reef areas within the region caused by natural disturbances as well as direct anthropogenic actions (Rodríguez-Ramírez et al., 2010). Loss of coral cover can be higher than 50 % depending on the location (Garzón-Ferreira & Díaz, 2003; Garzón-Ferreira & Kielman, 1994). The main factors causing long-term coral declines were considered to be natural disturbances such as hurricanes, bleaching events, epidemic diseases, and algal proliferation. Sedimentation, eutrophication, chemical pollution, overfishing, dynamite fishing, and nautical activities were identified as additional anthropogenic disturbances for Colombian Caribbean corals.

On the Caribbean coast close to the city of Santa Marta, coral formations develop in the Tayrona National Natural Park (TNNP) (Garzón-Ferreira & Cano, 1991). Although these corals are affected by inflow of sediment-rich freshwater (Garzón-Ferreira, 1998) and lack of adequate bottom structures for settlement (Werding & Erhardt 1976), they nevertheless show similar features to reef coral ecosystems such as highly diverse deep- and shallow water coral associations (Werding & Sánchez, 1989) and reef-like coral frameworks. Furthermore, the coral ecosystem of the TNNP is influenced by fluctuating environmental factors during the rainy season (May to November) but also by seasonal upwelling events (December to April), which can trigger a decrease in temperature and salinity changes (Andrade & Barton, 2005). Temperature changes from 30 °C to 22 °C and salinity increase from 33 to 38 have been reported (Petùs et al., 2007) from beginning until the end of upwelling.

Despite of the vast decline of corals due to increased sedimentation, reduction of light penetration, nutrient enrichment, diseases, and dynamite fishing, with mainly branching and foliose species such as *Acropora cervicornis* (80 %), *A. palmata* (60 %), *Agaricia tenuifolia* (80 %) and

Porites porites (almost 100 %) affected (Garzón-Ferreira & Cano, 1991), the coral formations of the TNNP have not been observed to exhibit bleaching over the last decades so far. Even during the "Caribbean Crisis" in 2005 (Wilkinson & Souter, 2008) only 1 – 5 % of the coral cover in TNNP were observed to bleach with a negligible mortality of less than 1 % as compared to up to 70 – 80 % bleached coral cover in other near-by non-upwelling locations such as Islas del Rosario-Cartagena or Islas San Bernardo (Rodríguez-Ramírez et al., 2008).

However, in November/December 2010, we observed moderate to high bleaching of the local coral communities of TNNP. Subsequently, we quantified its extent and followed the process of recovery during the consecutive months. Bleaching occurred after a strong El Niño phase which increased the sea surface temperature (SST) from 28 °C to 30 °C and a subsequent La Niña (IDEAM 2011) period usually leading to increased precipitation (Hoegh-Guldberg, 1999). Strong rain-fall affected coastal coral communities by a sudden decrease in salinity, large amounts of sediment-loaded freshwater and drastically increased turbidity.

Unlike real reef structures, coral communities of the TNNP are only poorly investigated. Their adaptation potential to changing environmental conditions, resilience and role as engineers for the functioning of ecosystem is not well documented so far. In this study we tested the hypothesis that corals in upwelling-exposed locations with increased wave action and turbulence have a higher resilience and recovering potential from bleaching events than corals in upwelling-sheltered locations.

Material and Methods

Like all bays in TNNP, the Bay of Gayraca (11.33°N, 74.11°W) is exposed to strong winds from the northeast during December to April and July to August, resulting in seasonal upwelling with strong SST decrease and an increase in salinity. Due to its orientation, the western site of the bay is stronger affected by waves and strong currents induced by upwelling than the eastern site.

Water temperature throughout the whole study was measured at a water depth of 10 m on an upwelling-exposed and -sheltered site in Gayraca (Fig. 1) by Hobo temperature loggers TidBit v2 (Onset) with a temporal resolution of 5 min and accuracy of ± 0.2 °C. Salinity was measured monthly on triplicate samples taken from a water depth of 10 m.

In December 2010, coral cover was quantified along 10 m transects (n = 5) on both sites of the bay (Fig. 1). In order to quantify bleaching and recovery of an upwelling influenced region in which coral formations develop, we used the BLAGRRA line-transect protocol (http://www.agrra.org/BLAGRRA) for the assessment of coral health.

Coral condition (categorized as normal, pale, bleached, dead/overgrown) and intercept length of every coral underneath the line-transect were determined, colonies marked and documented photographically. The same transects were monitored in March/April 2011 in order to quantify and qualify the process of coral recovery and/or mortality.

Prior to statistical analyses, one transect replicate for the sheltered site in 2010 was identified as outlier and excluded from further calculations. Benthic cover estimates were arcsine transformed according to Zar (1999). Differences in coral conditions between the sites and the years 2010 and 2011 were examined by a two-way ANOVA. A Holm-Sidak test was used for pairwise comparison. Arcsine transformed percentages of normal, bleached, pale and overgrown corals were the dependent variables and site and year were used as independent variables. One-way ANOVA was used to evaluate site-specific differences between bleached corals in 2010 and dead corals in 2011 with arcsine transformed percentages of bleached and dead corals as dependent variables. (SigmaPlot, 12.0, Copyright© 2011 Systat Software, Inc).

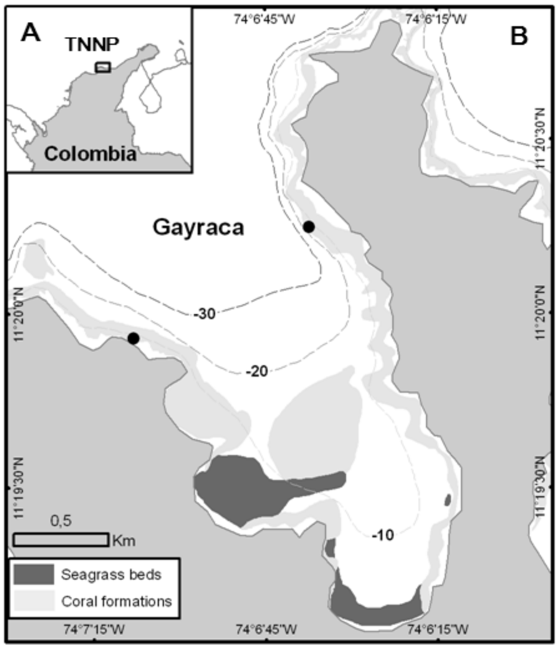

Figure 1: A. Location of the Tayrona National Natural Park (TNNP) in the Colombian Caribbean. B. Bay of Gayraca located in the TNNP. The circles indicate the permanent study sites. Depth contours are depicted with dashed lines. Source: (INVEMAR - SIAM, 2012).

Results

Maximal temperature in our study was recorded for October 2010 with 30.4 °C at the sheltered and 30.1 °C at the exposed site in the Bay of Gayraca (Fig. 2). In December 2010 maximal logged temperature was 28.2° for both sites. Minimal temperature was detected in February 2011 with 20.8° for the exposed and 21.1 °C for the sheltered site. In April minimal temperature recorded was 24.7 °C for both sites. Salinity was 36.2 in December 2010, 37.7 in January and 36.7 in April 2011 for the sheltered site and 37.2, 38.5 and 36.5 for the exposed site, respectively (Fig. 2).

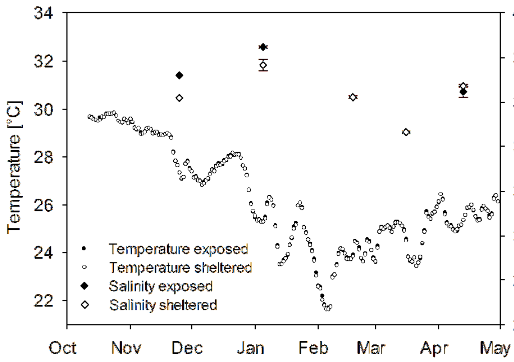

Figure 2: Temperature and salinity variation in Gayraca Bay from October 2010 to May 2011 at a depth of 10 m. Temperature is displayed as daily means for the exposed and sheltered site. Error bars represent the standard deviation.

Corals of the upwelling-exposed site at a water depth of 10 m had massive to encrusting growth forms and colonies of *Montastraea cavernosa*, *Diploria strigosa*, *D. labyrinthiformis* and *Colpophyllia natans* dominated the coral community. Benthic coral cover was 14 ± 6 % (mean ± SE) of which 8 ± 6 % were bleached in December 2010 (Fig. 3).

On the sheltered site, at the same water depth we found reef-like frameworks with higher coral diversity, benthic cover of 38 ± 10 % and *M. cavernosa, M. faveolata, M. franksii, D. strigosa, C. natans* and *Porites asteroides* as the predominant species among scleractinian corals. In December 2010, 34 ± 11 % of the corals at the sheltered site were bleached (Fig. 3). The species *M. faveolata* and *M. franksii* were severely affected on the sheltered site (Fig. 4) with an overall benthic cover of 16 and 25 %, respectively. Among the monitored corals, 100 % of *M. faveolata* and 88 % of *M. franksii* were bleached in December 2010 at the sheltered site. The remaining 12 % of the latter coral species were pale. No other coral species were found to have significant bleaching. The 19 % ± 3 pale corals accounted for 29% of all *M. cavernosa*, 13 % of *M. franksii*, 14 % of *D. strigosa* and 33 % of *P. asteroides* at the sheltered site.

Interestingly, both coral species *M. faveolata* and *M. franksii* did not occur on the exposed site of Gayraca Bay. Here, the corals affected by bleaching were mainly *M. cavernosa* and *D. labyrinthiformis,* which accounted for 46 and 12 % of the total benthic coral cover along a 50 m transect, respectively. The percentage of bleaching was 17 % for all *M. cavernosa* and 33 % for *D. labyrinthiformis* at the exposed site. The remaining 12 ± 8 % pale corals were distributed over 16 % of *M. cavernosa* and 22 % of *D. strigosa*.

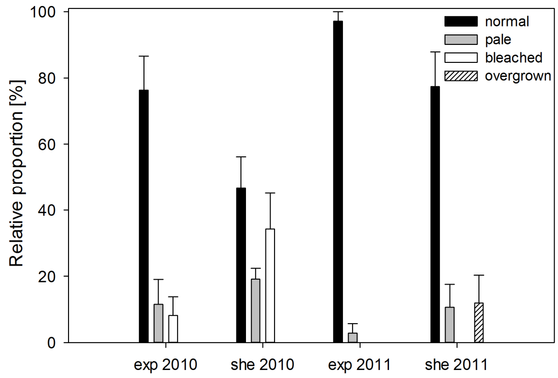

Figure 3: Relative proportion of the state of coral colonies for the exposed and sheltered site within the Bay of Gayraca for 2010 and 2011. Exp: exposed site, she: sheltered site. Data is shown as mean + SE of n = 5 transect replicates of 10 m length.

In April 2011, we observed full recovery from bleaching by all corals at the sheltered site except for the species *M. faveolata* and *M. franksii* of which 50 and 75 % were dead and completely overgrown by algae, respectively. On the exposed site, our surveys in March 2011 found that all corals had recovered except for 3 ± 3 % mainly consisting of pale *M. cavernosa* colonies. No dead or partly overgrown coral colonies could be identified at the exposed site of Gayraca Bay (Fig. 3).

During the upwelling event from December to April, coral colonies recovered on both sites of Gayraca Bay (Fig. 3.). The bleaching extent in December 2010 was more than three times higher at the sheltered than at the exposed site, with mainly *M. faveolata and M. franskii* affected – coral species that do not occur at the exposed site. All corals recovered from bleaching at the exposed site, whereas on the sheltered site 12 ± 8 % died and were overgrown by algae (Fig. 3).

Comparative statistical analyses (ANOVA) of the relative proportion of normal coral colonies as dependent variable for both sites within the bay revealed that corals recovered significantly ($p = 0.011$) from 2010 to 2011. With a significance level of < 0.05 ($p = 0.009$), we were able to show that coral bleaching at the sheltered site was higher than at the exposed site. It could not be statistically verified that the exposed site exhibited less dead/overgrown corals than the sheltered site. In 2011, we observed a trend that the sheltered site had more overgrown corals than the exposed site ($p = 0.16$).

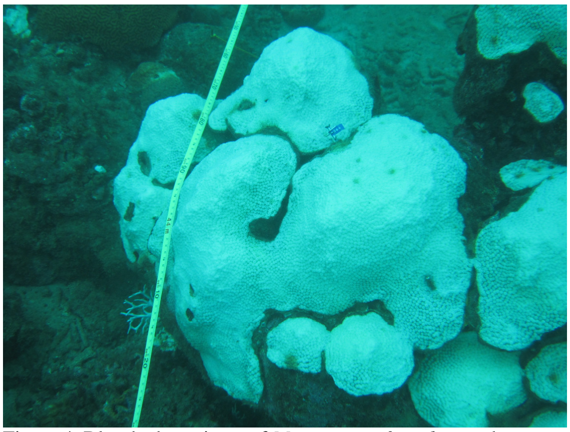

Figure 4: Bleached specimen of *Montastraea faveolata* at the sheltered site in Gayraca Bay.

Discussion

In this study we demonstrate that the extent of coral bleaching in the Tayrona National Natural Park in 2010 was different between two nearby locations within the same bay that differ in the degree of exposure to upwelling increased waves and current dynamics and species composition. We also found differences in the relative proportion of bleached corals within these sites. Upwelling-sheltered locations exhibited more than three times higher coral bleaching than -exposed locations. Our data for the relative proportion of bleached corals of 8 % for the upwelling-exposed site and 34 % for the sheltered site can be compared with data obtained by the Sistema Nacional de Monitoreo de Arrecifes Coralinos en Colombia (SIMAC). SIMAC detected a bleaching extent of 18 % for the Bay of Chengue (Vega-Sequeda et al., 2011), which is the neighboring bay to Gayraca in TNNP and can be classified as an upwelling-sheltered site.

The recovery of coral communities from bleaching differed between the sites of the same bay. Four months after bleaching over 97 % of the corals at the exposed site had recovered with only 3 % pale colonies. In contrast, the sheltered site exhibited 77 % of coral recovery and 12 % dead colonies. Data cannot be compared to previous coral bleaching events so far as the extent of bleaching was considered as negligible for the region (Rodríguez-Ramírez et al., 2008; Vega-Sequeda et al., 2008; Navas-Camacho et al., 2010).

It cannot be excluded that difference in bleaching of corals living at the exposed- and sheltered site might be a result of the specific coral species found at each site. The major bleached coral species *M. faveolata* and *M. franksii* were the most sensitive species to bleaching. They were predominantly found at the sheltered site of the bay. At the exposed site bleaching was mainly observed for *D. labyrinthiformis* and *M. cavernosa*. *D. labyrinthiformis* and *M. cavernosa* were mostly found to be pale on the sheltered site in December 2010. However, we observed that if the relative proportion of corals is compared between the upwelling-exposed and -sheltered site, the corals living under higher turbulence regime at the exposed site were more resilient to disadvantageous changes of the environmental parameters and had the potential to recover better from bleaching events.

We suggest that seasonal upwelling in TNNP has a mitigation effect on coral bleaching depending on the degree of exposure to waves and currents, which are enhanced during upwelling. We also hypothesize that seasonal upwelling enhances recovery due to the change of local hydrodynamics removing harmful reactive oxygen radicals and their permeable derivatives which are thought to be produced before bleaching (Lesser, 2006). Nakamura & van Woesik, (2001) observed that *Acropora* spp. coral colonies exposed to high water flow rates were more resistant to a combination of high SST and irradiance than colonies in low water flow habitats under the same conditions. Later Nakamura & van Woesik (2003) found that water flow also facilitated the recovery of *Stylophora* spp. from bleaching, supporting our results for the complete recovery of affected coral colonies at an upwelling-exposed site in the Bay of Gayraca. The suggested recovery effect from bleaching by increased water flow may be further enhanced by the decrease of SST (Riegl & Piller, 2003) and displacement of sediment-loaded turbid water by clearer and oxygenated water during upwelling. A possible effect of increased heterotrophic feeding by corals during plankton blooms associated with increased nutrient concentration during upwelling cannot be excluded. However, the upwelling of TNNP is known as a relatively oligotrophic upwelling from water depths of 200 – 300 m (Petús et al., 2007; Diaz-Pulido & Garzón-Ferreira, 2002). Nevertheless, the latter mentioned factors account for the whole upwelling region and are not site-specific like the difference in hydrodynamics.

The role of upwelling areas as possible refugia for coral reefs in times of increasing environmental stress was first proposed by Glynn (1996) and later evaluated by Riegl & Piller (2003). Chollett et al.

(2010) provided evidence that coastal upwelling only possesses a potential coral bleaching mitigation effect if warming and upwelling are synchronous, which is the case in TNNP. A coral bleaching mitigating effect induced by seasonal upwelling for the region of TNNP was suggested by Rodríguez-Ramírez et al. (2008) and Rodríguez-Ramírez et al. (2010) in order to explain why the region has not been affected during major bleaching events in the Caribbean. However, an investigation by the comparison of coral communities living in upwelling-exposed and -sheltered locations within the region, like in our study, was lacking. In order to identify the key factors controlling coral ecosystem functioning, we will focus our future research on the assessment of local hydrodynamics and water quality on small temporal and spatial scales between the sites with different degree of upwelling-exposure of the TNNP bays.

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References

Andrade C & Barton E (2005) The Guajira upwelling system. Cont Shelf Res 25(9): 1003-1022

Chollett I, Mumby PJ & Cortés J (2010) Upwelling areas do not guarantee refuge for coral reefs in a warming ocean. Mar Ecol Prog Ser 416: 47-56

Diaz-Pulido G & Garzón-Ferreira J (2002) Seasonality in Algal Assemblages on Upwelling-influenced Coral Reefs in the Colombian Caribbean. Bot Mar 45: 284-292

Garzón-Ferreira J (1998) Bahía de Chengue, Parque Natural Tayrona, Colombia. In Kjerfve B (ed) CARICOMP-Caribbean coral reef, seagrass and mangrove sites. Coastal region and small island papers 3, Paris, France: UNESCO, pp 115-126

Garzón-Ferreira J & Cano M (1991) Tipos, Distribución, Extensión y Estado de Conservación de los Ecosistemas Marinos Costeros del Parque Nacional Natural Tayrona. In Final Report (Invemar). Santa Marta, Colombia, p 82

Garzón-Ferreira J & Díaz J M (2003) The Caribbean coral reefs of Colombia. In Cortés J (ed) Latin American coral reefs Amsterdam, The Netherlands: Elsevier Science B.V, pp 275-301

Garzón-Ferreira J & Kielman M (1994) Extensive mortality of corals in the Colombian Caribbean during the last two decades. Colloquium Global Aspects Coral Reefs: Health and history. RSMAS, Univ. Miami, USA, pp 247-253

Glynn PW (1996) Coral reef bleaching: facts, hypotheses and implications. Glob Change Biol 2(6): 495-509

Hoegh-Guldberg O (1999) Climate change, coral bleaching and the future of the world's coral reefs. Mar Freshwater Res 50(8): 839

INVEMAR - SIAM. (2012). Sistema de Información Ambiental Marina de Colombia. - SIAM. Recuperado el 2 de Febrero de 2012 del Servicio Acceso a Datos del Instituto de Investigaciones Marinas y Costeras –INVEMAR. Santa Marta, Colombia

Lesser MP (2006) Oxidative stress in marine environments: biochemistry and physiological ecology. Annu Rev Physiol 68: 253-278.

Nakamura T & van Woesik R (2001) Water-flow rates and passive diffusion partially explain differential survival of corals during the 1998 bleaching event. Mar Ecol-Prog Ser 212(2): 301-304

Nakamura T, Yamasaki H & van Woesik R (2003) Water flow facilitates recovery from bleaching in the coral Stylophora pistillata. Mar Ecol-Prog Ser 256: 287-291

Navas-Camacho R, Rodríguez-Ramírez A, Reyes-Nivia MC, Gil-Agudelo DL & Garzón-Ferreira J (2010) Coral diseases and bleaching on Colombian Caribbean coral reefs. Rev. Biol. Trop. 58 (Suppl. 1): 95-106

Petùs C, García-Valencia C, Thomas F & Cessaraccio M (2007) Caracterización preliminar del proceso de surgencia costera de La Guajira a partir de observación satelital. In Informe final, Programa GEZ (ed.) Santa Marta, Colombia: Instituto de Investigaciones Marinas y Costeras – Invemar y Corporación Autónoma Regional de la Guajira - Corpoguajira, pp 53+anexos

Riegl B & Piller WE (2003) Possible refugia for reefs in times of environmental stress. Int J Earth Sci 92(4): 520-531

Rodríguez-Ramírez A, Bastidas C, Rodríguez S, Leão Z, et al. (2008) The effects of coral bleaching in southern tropical America: Brazil, Colombia and Venezuela. In Wilkinson C & Souter D (eds) The status of Caribbean coral reefs after bleaching and hurricanes in 2005. Townsville: Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre, pp 105–114

Rodríguez-Ramírez A, Garzón-Ferreira J, Batista-Morales A, Gil D L, Gómez-López D I, Gómez-Campo K, López-Londoño T, et al. (2010) Temporal patterns in coral reef, seagrass and mangrove communities from Chengue bay CARICOMP site (Colombia): 1993-2008. Rev Biol Trop 58 Suppl 3: 45-62

Vega-Sequeda J, Rodríguez-Ramírez A, Reyes-Nivia MC, Navas-Camacho R (2008) Formaciones coralinas del área de Santa Marta, estado y patrones de distribución espacial de la comunidad bentónica. Bol. Invest. Mar. Cost. 37(2): 87-105

Vega-Sequeda J, Navas-Camacho R, Gómez-Campo K, López Londoño T, & Duque D L (2011) Estado de los arrecifes coralinos. In Invemar, Informe del Estado de los Ambientes y Recursos Marinos y Costeros en Colombia: Año 2010. Serie de Publicaciones Periódicas No. 8. Santa Marta

Werding B & Erhardt H (1976) Los corales (Anthozoa y Hydrozoa) de la Bahía de Chengue en el Parque Nacional Tayrona (Colombia). An. Inst. Inv. Mar. Punta de Betín 8: 45-57

Werding B & Sánchez H (1989) The coral formations and their distributional pattern along a wave exposure gradient in the area of Santa Marta, Colombia. Medio Ambiente 10(2): 61-68

Wild C, Hoegh-Guldberg O, Naumann MS, Colombo-Pallotta MF, Ateweberhan M, Fitt WK, Iglesias-Prieto R, et al. (2011) Climate change impedes scleractinian corals as primary reef ecosystem engineers. Mar Freshwater Res 62(2): 205-215

Wilkinson C & Souter D (2008) Status of Caribbean Coral Reefs After Bleaching and Hurricanes in 2005. Wilkinson C & Souter D (eds) Townsville, Australia: Status of Caribbean Coral Reefs After Bleaching. Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre, p 152

Zar JH (1999) Biostatistical analysis. Prentice Hall, Upper Saddle River, USA