Monitoring coral reefs, seagrasses and mangroves in Costa Rica (CARICOMP)

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Abstract: The coral reefs, seagrasses and mangroves from the Costa Rican Caribbean coast have been monitored since 1999 using the CARICOMP protocol. Live coral cover at Meager Shoal reef bank (7 to 10m depth) at the Parque Nacional Cahuita (National Park), increased from 13.3% in 1999, to 28.2% in 2003, but decreased during the next 5 years to around 17.5%. Algal cover increased significantly since 2003 from 36.6% to 61.3% in 2008. The density of *Diadema antillarum* oscillated between 2 and 7ind/m^2, while *Echinometra viridis* decreased significantly from 20 to 0.6ind/m^2. Compared to other CARICOMP sites, live coral cover, fish diversity and density, and sea urchin density were low, and algal cover was intermediate. The seagrass site, also in the Parque Nacional Cahuita, is dominated by *Thalassia testudinum* and showed an intermediate productivity (2.7±1.15 g/m^2/d) and biomass (822.8±391.84 g/m^2) compared to other CARICOMP sites. Coral reefs and seagrasses at the Parque Nacional Cahuita continue to be impacted by high sediment loads from terrestrial origin. The mangrove forest at Gandoca, within the Refugio Nacional de Vida Silvestre Gandoca-Manzanillo (National Wildlife Refuge), surrounds a lagoon and it is dominated by the red mangrove, *Rhizophora mangle*. Productivity and flower production peak was in July. Biomass (14kg/m^2) and density (9.0±0.58 trees/100m^2) in Gandoca were relatively low compared to other CARICOMP sites, while productivity in July in Costa Rica (4g/m^2/d) was intermediate, similar to most CARICOMP sites. This mangrove is expanding and has low human impact thus far. Management actions should be taken to protect and preserve these important coastal ecosystems. Rev. Biol. Trop. 58 (Suppl. 3): 1-22. Epub 2010 October 01.

Key words: Cahuita, Gandoca, Caribbean, Costa Rica, coral reef, productivity, *Thalassia testudinum, Rhizophora mangle, Diadema antillarum,* mangrove, seagrass, CARICOMP.

Coral reefs, seagrasses and mangroves are the most productive coastal ecosystems in the tropics. However, their productivity, biodiversity and importance for the well being of local communities and their importance to the global living systems is compromised due to existing natural and human impacts (Short & Wyllie-Echeverria 1996, Valiela *et al*. 2001, Hughes *et al*. 2003, Pandolfi *et al*. 2003, Hoegh-Guldberg *et al*. 2007, Waycott *et al*. 2009). Monitoring programs are being set up to evaluate those changes. In the Caribbean, the international collaborative program CARICOMP (Caribbean Coastal Marine Productivity) has been monitoring mangroves, seagrasses and coral reefs (CARICOMP 1997a, Linton & Fisher 2004). In Costa Rica, the reef and seagrasses at Cahuita National Park (PNC), and mangroves of the Gandoca-Manzanillo National Wildlife Refuge (REGAMA) have been monitored following the CARICOMP protocol since 1999. Seagrasses at Cahuita are found in the coral reef lagoon (Risk *et al*. 1980, Cortés & Guzmán 1985a, Cortés & Jiménez 2003), and are therefore closely associated, while the mangroves of Gandoca are approximately 30 km south of Cahuita (Coll *et al*. 2001).

The objective of this paper is to summarize and integrate the tendencies of the permanent CARICOMP monitoring stations of Costa Rica (coral reef, seagrass and mangrove) and compare them with other studies in the region.

MATERIALS AND METHODS

Site descriptions

The climate of the Caribbean coast of Costa Rica consists of two rainy seasons, November to March and June to August. Annual rainfall rate in this southern section of the Caribbean coast is lower (2 500mm) than in the northern section (6 000mm). The micro-climate within REGAMA is characterized by nightly rains and ample periods of sunlight during the day (Herrera 1984, Alfaro 2002). Tides are mixed, mainly diurnal, and range between 30 to 50cm (Lizano 2006). Wave direction depends on the position of the Intertropical Convergence Zone and is mainly from the northeast between January and June, and from the east from July to December (Lizano 2007). Currents flow from northwest to southeast, with small eddies in the opposite direction (Cortés 1994), which transport terrestrial sediments and contaminants derived from deforested and urbanized lands in upstream watersheds and coasts (Cortés 1981, 1994, Cortés & Risk 1985, Fonseca & Cortés 2002). These sediments have been the main cause of coral reef and seagrass degradation during the last 50 years, combined with other increasing natural and anthropogenic disturbances (Cortés *et al*. 1992, 1994, Fonseca & Cortés 2002, Cortés & Jiménez 2003, Fonseca 2003, Roder 2005, Roder *et al*. 2009).

Coral reef and seagrasses of Cahuita National Park (PNC)

PNC is located on the southern Caribbean coast of Costa Rica (Fig. 1). It was created in 1970 and consists of 1 100ha of lowland rainforest and 22 400ha of marine territory, of which 600ha correspond to coral reef substrate. This is the largest and most studied fringing coral reef and associated seagrasses of Costa Rica (Cortés & Risk 1985, Cortés & Jiménez 2003, Fonseca 2003, Cortés 2009a). The coral reef at PNC consists of three reef crests; the main one (5 km long) along the front of Punta

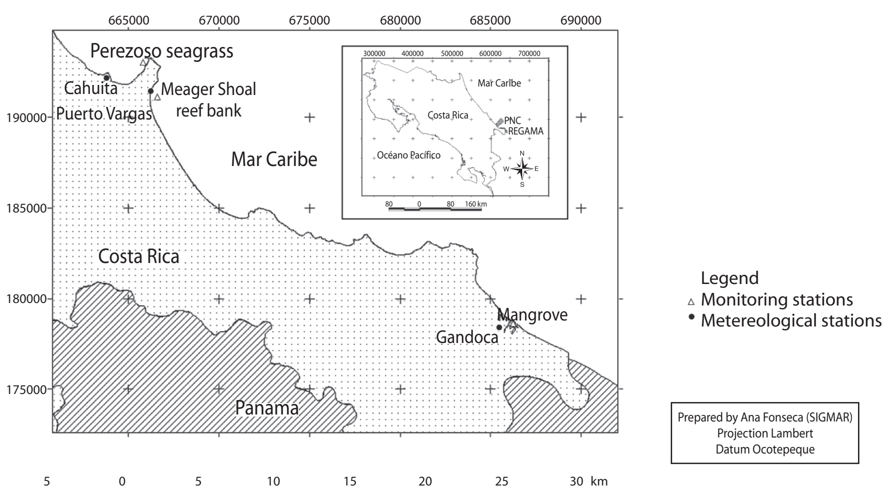

Fig. 1. Map of CARICOMP sites in Costa Rica.

Cahuita and the other two on either sides of this point. A narrow spur-and-groove system reaches depths of 10-15 m on the fore-reef of the main crest. Several small patch reefs and seagrass beds occur in the lagoon and there are several offshore carbonate banks (Risk *et al*. 1980, Cortés & Risk 1985). This reef also has one of the highest diversities in the country, including: three species of stony hydroids (Cortés 1992), 31 species of zooxanthellate scleractinian corals (Cortés & Guzmán 1985b, Cortés 2009b), six species of azooxanthellate corals (Cortés 2009b) and 19 species of octocorals (Guzmán & Cortés 1985, Breedy 2009). There are also four species of seagrass (Wellington 1974, Cortés & Salas 2009).

The coral reef at PNC is considered an economic asset to the local region estimated at over US $1.4 million a year (Blair *et al*. 1996). The population of Cahuita increased from 3 000 to 4 000 inhabitants in the last 13 years, and it receives more than 50 000 tourists per year (MINAE pers. comm.). The main economic activities in the town are tourism and fishing (Cortés in prep.).

The coral reef monitoring site is the reef bank known as Meager Shoal (9º43'50" N 82º48'32" W), located 1km offshore from the beach of Puerto Vargas and south from the main reef crest of Cahuita (Fig. 1). It has a circular area of about 10 000m^2, and the base of the bank is 10m deep while the top is at 7m. Corals were restricted to the top and the dominant species were *Agaricia agaricites*, *Porites astreoides*, *Siderastrea siderea* and *Montastraea faveolata*. Other coral species present were *Mycetophyllia* spp., *Madracis decactis, Dichocoenia stokesii* and *Siderastrea radians*. This reef bank was surrounded by terrestrial mud, which was easily re-suspended by the prevailing currents and strong waves. There are 10 permanent transects located at this site (Fonseca *et al*. 2006).

The seagrass monitoring site is known by local fishermen as "Perezoso" (9°44'13.3" N-82°48'24" W), located 500m north of the Perezoso (Sloth) creek, within the lagoon of the fringing reef of Cahuita (<1m deep). The site is dominated by turtle grass, *Thalassia testudinum*, intermixed with manatee grass, *Syringodium filiforme* (Risk *et al*. 1980, Cortés & Guzmán 1985a, Paynter *et al*. 2001, Fonseca *et al*. 2007a, Nielsen-Muñoz & Cortés 2008). Flowering of *T. testudinum* occurred between March and June (Fonseca *et al*. 2007a, Nielsen-Muñoz & Cortés 2008).

The permanent station for atmospheric temperature and rainfall measurements at PNC was located in the park rangers' house at Puerto Vargas (9º43'56" N-82º48'58" W).

Mangrove of the Gandoca-Manzanillo National Wildlife Refuge (REGAMA)

The REGAMA is located at the south-eastern most tip of the Caribbean coast of Costa Rica (Fig. 1). It is surrounded by the Sixaola River at the Panama-Costa Rica border to the east, a row of mountains of the Talamanca Cordillera to the south and on the north side by the Caribbean Sea (Fig. 1). It was created in 1985 and has a territory of 5 013 terrestrial ha and 4 436 marine ha, 80% of it is privately owned and 20% is owned by the government. The Gandoca wetlands are protected by the REGAMA and were designated as a RAMSAR site of international importance in 1995. Gandoca is the largest, least disturbed and most studied mangrove in the Caribbean coast of Costa Rica (Coll *et al*. 2001). Only at Gandoca and Corcovado, in the south Pacific coast of Costa Rica, is the tropical rain forest to mangrove continuum preserved (Cortés 1991).

The mangrove is located in the south-east section of the refuge, around the Gandoca lagoon. The area of the lagoon and the surrounding vegetation is 266ha, and the mangrove alone has an area of 12.5ha. It is dominated by the red mangrove *Rhizophora mangle*, with *Avicennia germinans* (black mangrove), *Laguncularia racemosa* (white mangrove) and *Conocarpus erectus* (buttonwood) also present. Moving inland, the mangroves gradually change into a tropical rain forest (Coll *et al*. 2001). Land use in adjacent areas includes banana and forestry plantations. Levels of pesticides in the lagoon were very low (Coll *et al*. 2004). Water exchange between the lagoon and the ocean depends on precipitation and run-off. There is more freshwater in the system than marine water that enters. The lagoon outlet varies in size, from 0 to several meters wide, which affects the water table in the mangrove soil during the year but doesn´t seem to affect the trees (Cortés 1998).

The mangrove monitoring site (9°35'23" N-82°35'54" W) was located approximately 300m inwards from the mouth of the Gandoca lagoon (Fig. 1). The dominant species was the red mangrove *Rhizophora mangle* (Fonseca et al. 2007b). The meteorological station in REGAMA was located about 1.5 km from the monitoring site (9º35'11.2" N-82º36'04." W), at the house owned by Aquiles Rodríguez, an active member of the Gandoca community and CARICOMP volunteer.

Methods

We used the Caribbean Coastal Marine Productivity (CARICOMP Level I and II) methodology (http://isis.uwimona.edu.jm/centres/cms/caricomp/carinew.htm) to compare our monitoring results with those from other Caribbean countries. This protocol was established in the region since 1990. In Costa Rica, attempts to set up a permanent station at the coral reef of Cahuita were carried out in 1997, but without local community involvement the rods marking the sites were frequently lost (Cortés 1998). In 1999 new locations in the three ecosystems were marked and although data is only complete for some years, they have been evaluated yearly since. Concurrently, the local communities were educated about the importance of marine and coastal ecosystems and trained to collaborate with the scientists to gather information, specially the weekly physical measurements.

Daily measurements

Continuously recording temperature sensors gathered air and water temperature information every 15 minutes; precipitation was measured in the meteorological stations by the park rangers and volunteers.

Weekly measurements

Weekly, volunteers from the local communities measured surface water temperature and salinity in Cahuita.

Coral reef

Meager Shoal has 10 permanent 10m long transects, and substrate relative cover is assessed yearly with the continuous intercept chain method, as is sea urchin density using the 1m wide belt method. Additionally, four transects (20x2m) were set to evaluate coral colony density and diseases. On September 13 2000, ten samples were taken to assess the algal biomass. From 1999 to 2005, two water samples (2 liters each), were taken during the rainy and dry seasons to determine the suspended particulate matter (SPM). Fish composition and density were evaluated from 2005 to 2007 following the AGRRA (Atlantic and Gulf Rapid Reef Assessment) protocol, i.e. 30x2 m belt transects (n=10), and in 2004, 2005 and 2007 using the REEF (Reef Environmental Education Foundation) rover diver method. Water temperature was recorded with an underwater temperature sensor, salinity with a refractometer and transparency with a Secchi disk in 1999, 2000 and 2001.

Seagrasses

The first year, samples (n=6) were taken monthly, from March 1999 to April 2000, in order to determine seasonal productivity. Data from May and December, 1999 and February and March 2000 could not be collected because of water turbulence and low visibility. Based on the monthly sampling between 1999 and 2000, June showed the highest productivity and February the lowest. Productivity was supposed to be evaluated afterward in these two months yearly; however, in recent years, rough seas precluded data taking in July. Only one month was sampled in 2001, 2003, 2006 and 2007, two in 2004, three in 2000 and 2005 and four in 2008. At present, there is an underwater temperature sensor to monitor the water temperature around the seagrasses at 15 min intervals. At the same time, the local community was educated about the importance of seagrasses and scientific research and on gathering information, specially marking the shoots for growth measurements.

Mangrove

Three 10x10m plots were established in 1999 to evaluate biomass, productivity, seedlings and forest structure. They were located in an accessible area, close to the boundary between the mangrove and the lagoon's water body. There was a permanent underwater sensor to monitor the water temperature within the mangrove roots (at a depth of 0.1m). Unfortunately, the mangrove plots were lost due to flooding in January 2005, so new ones have been established. The first year, samples were taken monthly, from June 1999 to March 2000, to determine the productivity peaks. During the rainy season, July showed the highest productivity. Therefore, productivity was evaluated again in July 2000, 2001, 2004, 2007 and 2008. At the same time, the local community was educated about the importance of mangroves and trained to help scientific studies, specially collecting litter fall from the productivity boxes.

Statistical analysis

Part of the data sets (1999-2004) were analyzed in previous papers (Fonseca *et al*. 2006, 2007a, b). Since data sets were complete only for some years, repeated measures analysis was not applied (von Ende 1993). Normality and heterogeneity of variances were tested on all the data sets, and transformed when possible.

Coral reef and seagrass data were normalized and analyzed with one-way ANOVA's and Bonferroni or Tukey post hoc tests depending on sample size (Underwood 1997). Variables for forest structure and productivity determination were transformed to a normal distribution with log in base 10. A factorial MANOVA was carried out, and because there was no interaction between the independent variables "plot" and "date", the main effect of "date" was tested with an ANOVA. The data of seasonal productivity could not be normalized and was analyzed with the non parametric test of Kruskall Wallis (H) (Underwood 1997).

RESULTS

Atmospheric temperature and rainfall

In the last 10 years, air temperature oscillated between 22.5 and 35.1°C, averaging around 26.5°C at PNC (Fig. 2) and between 20.7 and 32.1°C, with an average around 26°C

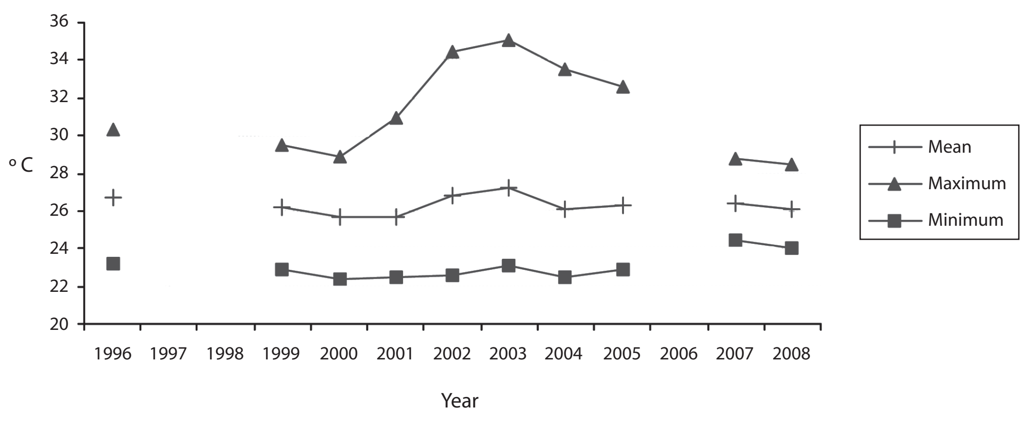

Fig. 2. Air temperature at Puerto Vargas, Parque Nacional Cahuita (PNC), 1996 to 2008.

at REGAMA (Fig. 3). Yearly rainfall ranged from approximately 1400 to 4000 mm at PNC and from approximately 1400mm at REGAMA (Fig. 4). The warmest months were May to June and September to October at both locations.

Water temperature, salinity and suspended particulate matter

In PNC, water temperature at 7m depth ranged from 26.6 to 29.6°C (Fig. 5) and from 25.3 to 33.1°C at 1.5m depth (Fig. 6). The maximum water temperature was recorded in 2003 and the minimum in 2001. Salinity at the PNC coral reef ranged from 34.2±1.2 to 37.8±0.8 PSU (n=19) and the mean Secchi depth was 3.5±2.2 m (n=19). Suspended particulate matter ranged from 4.1 to 34.5mg/l, with an average of 17.5±2.4 mg/l.

In REGAMA, water temperature within the mangrove roots ranged from 23.7 to 30.5°C, with spikes as low as 21.9°C and as high as 36.1°C. The highest water temperatures were in October 2004 and the lowest temperatures in February 2001 (Fig. 7). Salinity of interstitial waters ranged from 6 PSU (April) to 14 PSU (September), with an average of 8.2±4.1 between 1999 and 2009.

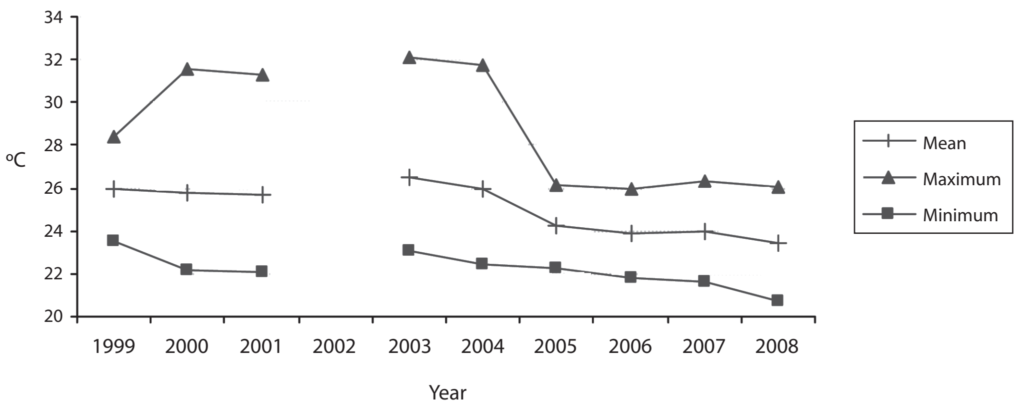

Fig. 3. Air temperature at Gandoca, Refugio Nacional de Vida Silvestre Gandoca-Manzanillo (REGAMA), 1999 to 2008.

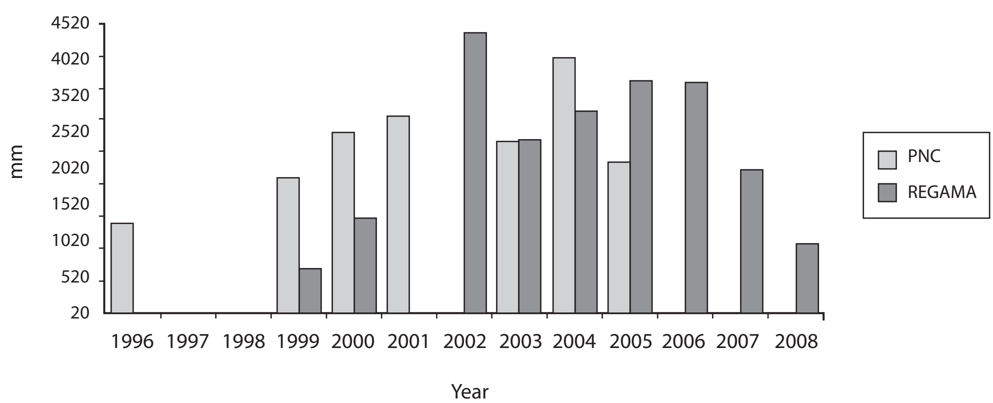

Fig. 4. Annual rainfall at PNC and REGAMA, 1996 to 2008.

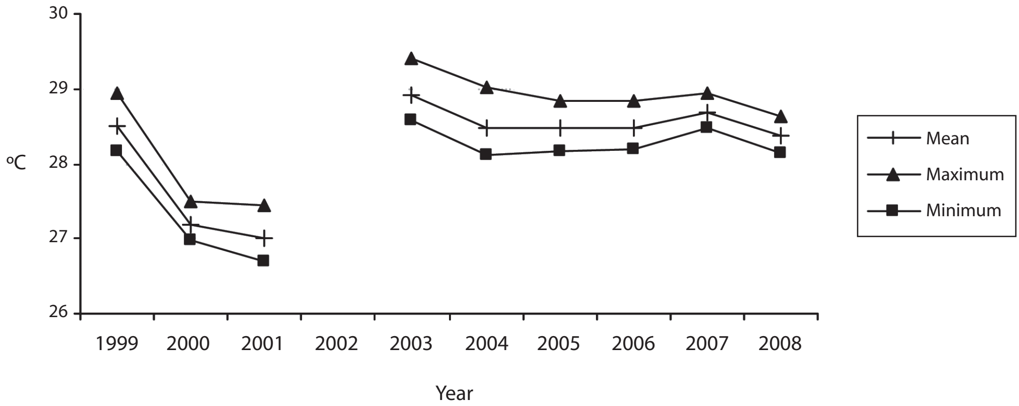

Fig. 5. Water temperature at the bank reef of Meager Shoal (PNC), 7m deep, from 1999 to 2008.

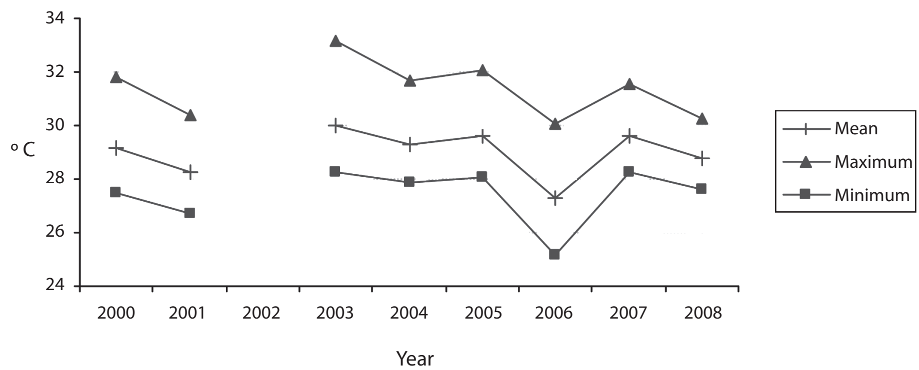

Fig. 6. Water temperature at the seagrass bed of Peresozo (PNC), 1.5m deep, from 2000 to 2008.

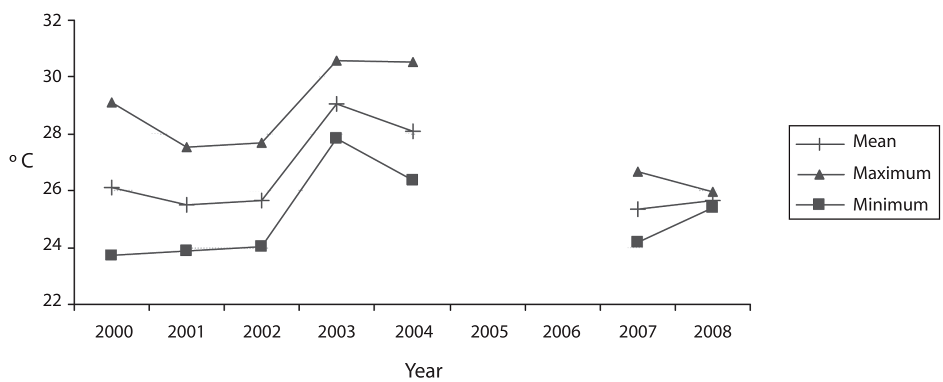

Fig. 7. Water temperature at the mangrove of Gandoca (REGAMA), 0.5m deep, from 2000 to 2008.

Overall, temperature seems to be decreasing, from 2003 to 2008 at the reef site (Fig. 5), but was higher than previous recorded years. The seagrass site (Fig. 6) also presents a decrease in temperature from a high in 2003 to levels similar to those recorded in previous years.

Coral reef

Live coral cover ranged from a low of 13.3% in 1999 to a high of 28.3% in 2003, dropping to a little less than 20% (with difference less than 3%) from 2005 to 2008. However, non-coralline algae increased 20% ($F=6.9$, $df=1$, $p<0.05$), and coralline algae decreased 11% ($F=17.9$, $df=1$, $p<0.05$). Total algae cover was higher than the live coral cover, and has an increasing trend, especially between 2000 and 2004 ($F=7.2$, $df=1$, $p<0.05$) (Fig. 8). Algal biomass was 1.92±1.29g/100m^2 in 2000. Turf algae (<1cm high) was dominant and macroalgae biomass was low.

The mean density of coral colonies has been decreasing, from as high as 4.6 colonies/m^2 in 1999 to 3.0 colonies/m^2 in 2004 (using the AGRRA method). In 2008, using the CARICOMP method, there were 2.3±0.4 colonies/m^2 in areas with dense cover and 0.5±0.3 colonies/m^2 in lower density areas. The dominant coral species were *Agaricia agaricites*, *Porites astreoides*, and *Siderastrea siderea*. The proportion of affected colonies by diseases, injuries and bleaching decreased from 24% in 2000 to 11% in 2004; however, but the difference is not statistically significant ($F=0.7$, $df=1$, $p>0.05$) (Fig. 9). In both years White Plague Disease (WPD) and Dark Spot Disease I (DSD-1) were the main diseases. Diseases affected mainly colonies of *S. siderea*, and bleaching was seen mainly in *S. siderea* and *P. astreoides*. Black Band Disease (BBD), Yellow Band Disease (YBD), Dark Spot Disease (DSD-II), White Band Disease (WBD) and *Aspergillosis* (ASP) were not observed. No diseased or bleached corals were encountered in 2008.

Density of *Diadema antillarum* (between 2 and 7ind/m^2) and *Eucidaris tribuloides* were low in Meager Shoal, though there was an increase in the first species. Density of *Echinometra viridis* was relatively high, yet decreased significantly from 20 to 0.6ind/m^2 between 2000 to 2008 ($F=10.8$, $df=1$, $p<0.05$) (Fig. 10).

Fish density ranged from 8.8 to 17.3ind/100m^2, with the parrot fishes the most abundant group. The largest fish were encountered in 2006 (20cm angelfishes) and most fishes had a mean size of less than 15cm with the AGRRA protocol (Table 1). Using the REEF protocol, pomacentrids and labrids were the most abundant fishes in Meager Shoal (Table 2). A total of 51 fish species were encountered after four years of fish counts (Table 2).

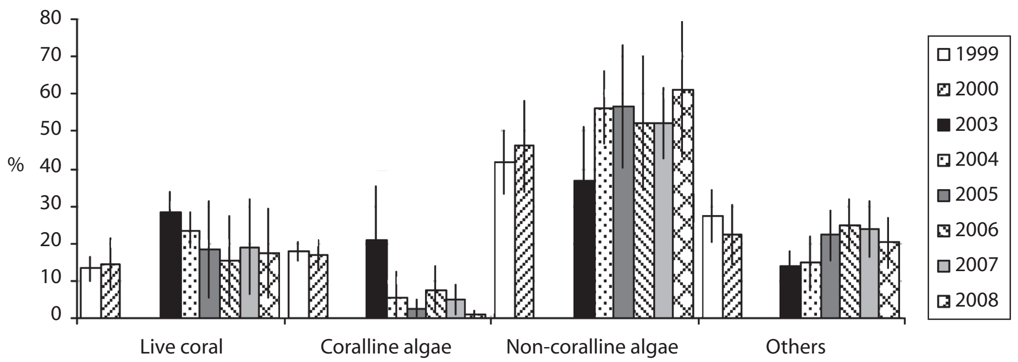

Fig. 8. Reef substrate relative cover at Meager Shoal (PNC), from 1999 to 2008.

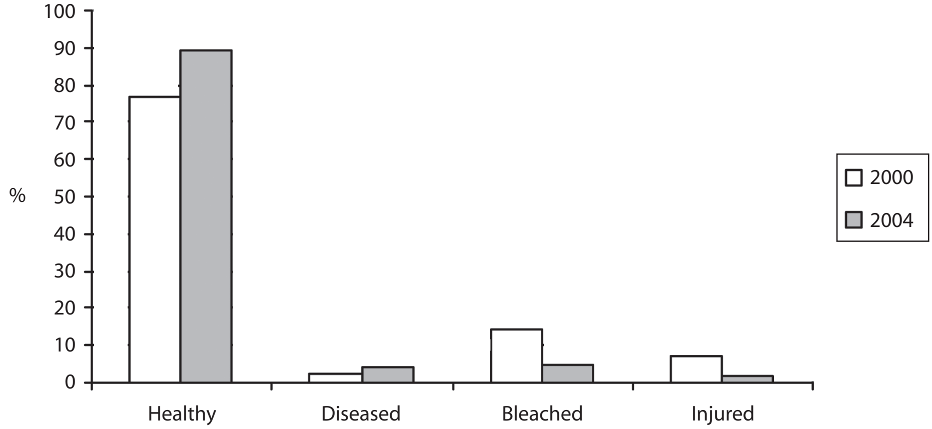

Fig. 9. General condition of coral colonies at Meager Shoal (PNC) in 2000 and 2004.

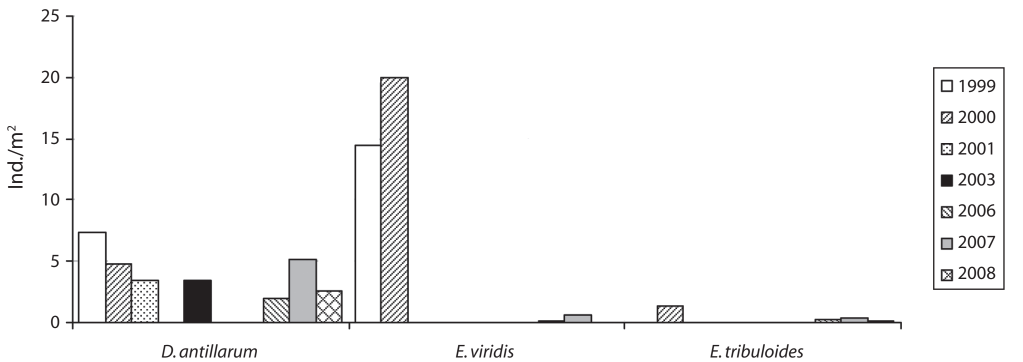

Fig. 10. Density (individuals/m^2) of the sea urchins, *Diadema antillarum, Echinometra viridis* and *Eucidaris tribuloides* at Meager Shoal (PNC), 1999 to 2008.

Seagrasses

Mean length, width and area of *Thalassia testudinum* leaves and Leaf Area Index have decreased from the 2000 survey compared to 2008 (Table 3). Sexual reproduction was observed between March and June. Productivity was highest in June and lowest in February (Fig. 11). Between 1999 and 2008, productivity decreased from 3.1 to 0.24g/m^2/day (Fig. 12). Turnover rate was also higher in 1999-2000 than the rest of the period, and has remained relatively stable since 2001 around 4% (Fig. 13). Shoot density has oscillated between 900 and 1 500shoots/m^2, with an outlier of 300shoots/m^2 in 2006 (Fig. 14). Density was considerably higher in April 1999, compared to September 1999 and March 2000 (F=3.65, df=8.95, p<0.05).

There are highly significant differences between years in terms of productivity (ANOVA, F=13.13; df=4.47, p<0.000; Fig. 12). The Tukey *a posteriori* test indicates that differences are highly significant (p<0.001) during 1999-2003 and the remaining years.

TABLE 1

Mean density and size of reef fishes in Meager Shoal (7m depth), 2004 (n transects=5) and 2005-2007 (n=10), after the AGRRA protocol

		Surgeonfishes	Parrotfishes	Grunts	Snappers	Seabasses	Angelfishes	Butterflyfishes	Leatherjacketa	Other	Total density
Density (#/100 m^2)	2005	1.50	5.17	0.17	0.83	1.00	0.17	0.83	0.17	2.00	11.8
	2006	0.83	2.50	1.50	0	1.33	0.83	0.50	0.17	1.17	8.8
	2007	3.83	4.00	0.83	1.00	3.17	1.17	0.50	0.17	2.67	17.3
Mean size (cm)	2005	15.50	13.40	15.50	17.58	15.50	15.50	7.42	8.00	12.33	
	2006	12.50	9.88	15.50	0	14.25	20.22	15.50	8.00	10.63	
	2007	14.26	16.93	15.50	15.50	13.50	25.50	8.67	15.50	12.00	

Fish counts were done by the same observer.

Turnover rate was also significantly different between years (ANOVA, F=8.327, p=0.000; Fig. 13), specifically during 1999-2000 and the remaining years (Tukey, p<0.01). Seagrass density was significantly lower in March 2000 when compared to March 1999 and March 2001 (F=4.25, df=4, p<0.05) (Fig. 14). Mean seagrasses biomass (*T. testudinum*) at Perezoso in March, from 1999 to 2008 has oscillated between a minimum of 650g/m^2 in 2005 and a maximum of 1 500 g/m^2 in 2006 (Fig. 15). Biomass decreased with time (F=3.84, df=4, p<0.05) and was significantly lower in 2005 than in 1999; however, it has gone up since then, to some of the highest levels so far. Seagrass biomass showed a high inverse correlation with mean (r=-0.87), minimum (-0.66) and especially with maximum temperature (-0.97). Productivity also showed a high inverse correlation with maximum temperature (-0.74).

Mangrove

The variables measured to determine forest structure showed no significant differences between years (F=0.32, df=4,160, p>0.05). Mean circumference at breast height of *R. mangle* was 46.0±31.3cm, prop root length 2.2±1.2m, trunk length 2.5±2.8m, tree height 11.8±2.2m, trunk diameter 14.8±9.8cm, basal area 22.9±9.1m^2/ha, and trunk volume 0.3±0.2m^3. With a mean density of 9.3±1.3trees/10 m^2, mean biomass was 4.6±0.7kg/m^2, after Golley *et al*. (1962), and 13.9±5.6kg/m^2 using Cintron and Schaeffer-Novelli (1984) equation. Sapling mortality from 1999 to 2000 was 46%, and 66.4% during 2007-2008; mean sapling height was 45.2±18.8cm.

Total productivity was significantly higher in July (H=76.43, df=9, p<0.05) and averaged 156.6±37.7g/m^2/month. Flower production was also significantly higher in July (H=128.95, df=9, p<0.05), while fruit production was low and highly variable without significant difference between months (H=15.09, df=9, p>0.05). Leaves corresponded to 67% of total litter fall, flowers 13%, bracts 7%, fruits 7%, branches 6% and 0.21% is miscellaneous material.

TABLE 2

Relative abundance of reef fishes in Meager Shoal, 2004-2007, after the REEF protocol (S=Single individual; F=Few, 2-10 individuals; M=Many, 11-100 individuals; A=Abundant, > 100 individuals), 0=absent; n.d.=no data

Species	Family	Relative abundance		
		2004	2005	2007
Megalops atlanticus	Megalopidae	S	S	S
Holocentrus adscensionis	Holocentridae	0	0	F
Holocentrus rufus	Holocentridae	S	0	0
Holocentrus vexillarius	Holocentridae	0	0	F
Scorpaena sp.	Scorpaenidae	0	S	0
Cephalopholis cruentata	Serranidae	F	F	0
Epinephelus cruentatus	Serranidae	0	0	M
Epinephelus guttatus	Serranidae	0	0	F
Serranus flaviventris	Serranidae	0	M	M
Gramma loreto	Grammatidae	0	0	S
Priacanthus arenatus	Priacanthidae	0	0	M
Caranx ruber	Carangidae	0	0	F
Lutjanus jocu	Lutjanidae	0	F	F
Lutjanus mahogoni	Lutjanidae	0	F	F
Lutjanus synagris	Lutjanidae	0	S	0
Ocyurus chrysurus	Lutjanidae	F	F	F
Anisotremus moricandi	Haemulidae	0	0	F
Anisotremus virginicus	Haemulidae	0	F	0
Haemulon macrostomum	Haemulidae	0	0	S
Haemulon sciurus	Haemulidae	0	0	F
Odontoscion dentex	Sciaenidae	F	F	F
Chaetodipterus faber	Ephippidae	0	F	0
Chaetodon capistratus	Chaetodontidae	F	F	F
Chaetodon ocellatus	Chaetodontidae	0	F	F
Holacanthus tricolor	Pomacanthidae	0	S	S
Pomacanthus arcuatus	Pomacanthidae	0	S	F
Abudefduf saxatilis	Pomacentridae	F	0	F
Chromis cyanea	Pomacentridae	0	0	S
Chromis multilineata	Pomacentridae	0	F	0
Microspathodon chrysurus	Pomacentridae	0	S	F
Stegastes diencaeus	Pomacentridae	0	M	0
Stegastes dorsopunicans	Pomacentridae	M	A	M
Stegastes partitus	Pomacentridae	F	M	M
Amblycirrhitus pinos	Cirrhitidae	F	F	F
Sphyraena barracuda	Sphyraenidae	0	0	S
Bodianus rufus	Labridae	F	M	M
Halichoeres bivittatus	Labridae	0	M	0
Halichoeres garnoti	Labridae	0	0	S
Thalassoma bifasciatum	Labridae	F	A	A
Scarus croicensis	Scaridae	0	0	F
Scarus iseri	Scaridae	0	F	0
Scarus taeniopterus	Scaridae	0	F	F

TABLE 2 (Continued)

Relative abundance of reef fishes in Meager Shoal, 2004-2007, after the REEF protocol (S=Single individual; F=Few, 2-10 individuals; M=Many, 11-100 individuals; A=Abundant, > 100 individuals), 0=absent; n.d.=no data

Species	Family	Relative abundance		
		2004	2005	2007
Sparisoma aurofrenatum	Scaridae	0	F	M
Sparisoma chrysopterum	Scaridae	0	0	F
Sparisoma rubripinne	Scaridae	0	M	F
Sparisoma viride	Scaridae	0	F	F
Ophioblennius atlanticus	Blenniidae	0	F	S
Acanthurus bahianus	Acanthuridae	0	S	F
Acanthurus chirurgus	Acanthuridae	0	0	F
Acanthurus coeruleus	Acanthuridae	F	A	M
Cantherhines pullus	Monacanthidae	0	F	S
Canthigaster rostrata	Tetraodontidae	F	F	M

TABLE 3

Mean length, width and area of Thalassia testudinum *leaves, and Leaf Area Index at Río Perezoso (PNC)*

Year	Length (cm)	Width (mm)	Mean Area (cm^2)	Leaf Area Index (m^2 leaf/m^2 surface)
2000	13.4±5.4	9.0±1.8	7.4±4.3	3.4±1.6
2008	5.1±0.7	6.7±1.9	2.5±0.8	1.4±0.8

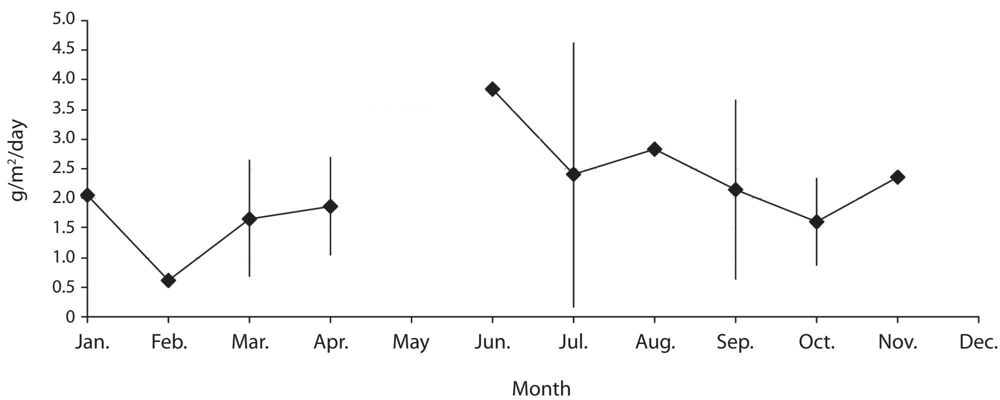

Fig. 11. Monthly average (1999-2009) of *Thalassia testudinum* productivity at Perezoso (PNC).

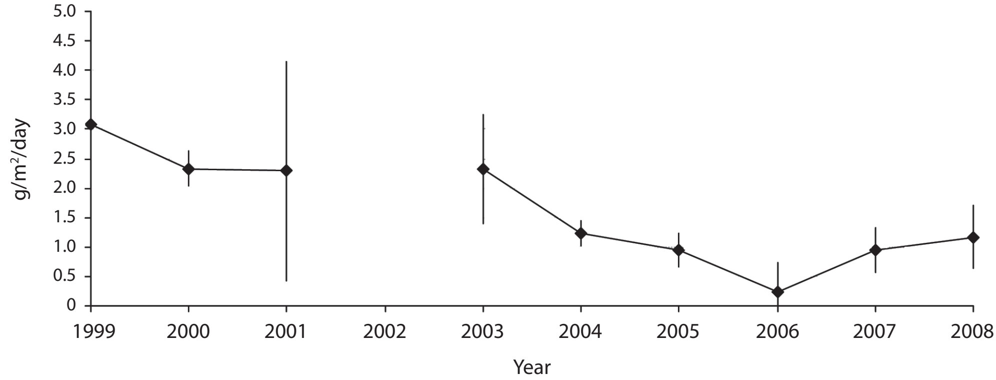

Fig. 12. Productivity (±standard deviation) of *Thalassia testudinum* at Perezoso (PNC), 1999 to 2008.

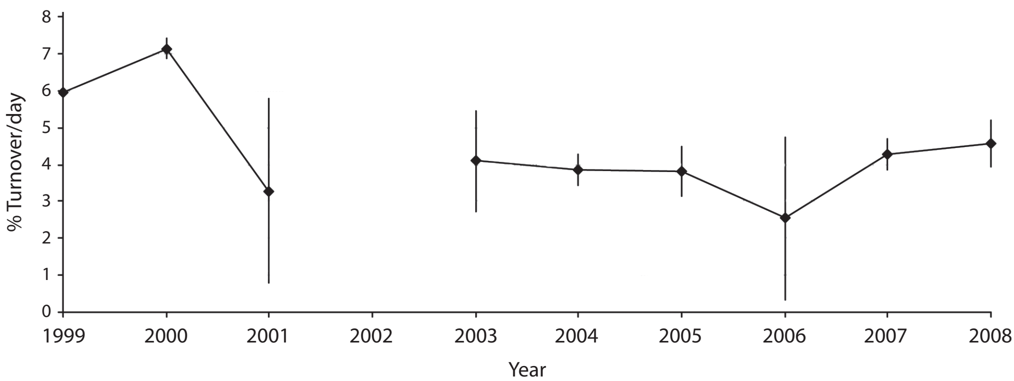

Fig. 13. Turnover rate (±standard deviation) of *Thalassia testudinum* at Perezoso (PNC), 1999 to 2008.

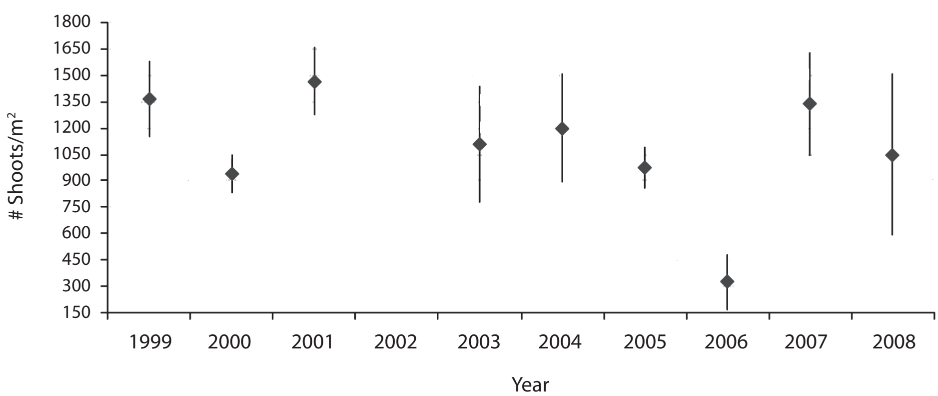

Fig. 14. Density (±standard deviation) of *Thalassia testudinum* at Perezoso (PNC), 1999 to 2008.

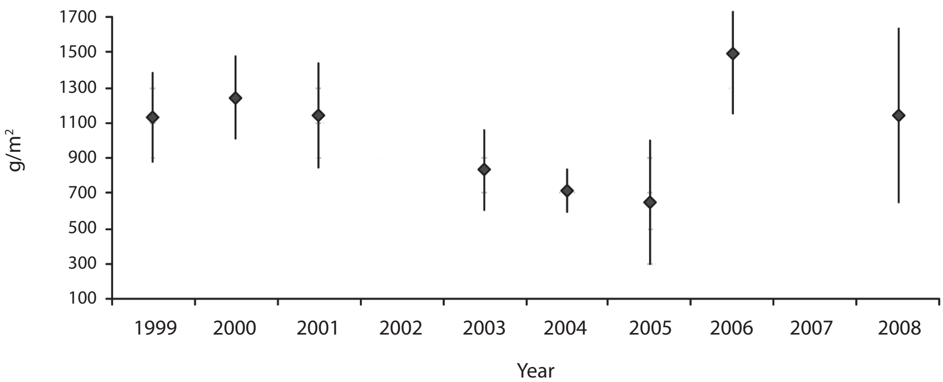

Fig. 15. Biomass (± standard deviation, n=4) of *Thalassia testudinum* at Perezoso (PNC), 1999 to 2008.

Yearly productivity was significantly higher in July 1999 than the same month in 2001 and 2004 ($F=12.34$, $df=3$, $p<0.05$, Fig. 16). However, when this period is compared to 2007-2008, productivity is currently significantly higher ($F=13.26$, $df=3$, $p<0.001$). The water table in the mangrove forest rises to 33 cm above the floor and the salinity is as low as 7PSU.

DISCUSSION

Coral reef

Water temperatures were optimal for coral growth at the study site, which is close to the corals upper tolerance level. But, in 2003 and 2005 there were warming events that caused coral bleaching (Fonseca *et al*. 2006, McField *et al*. 2008, Fonseca & Nielsen-Muñoz in

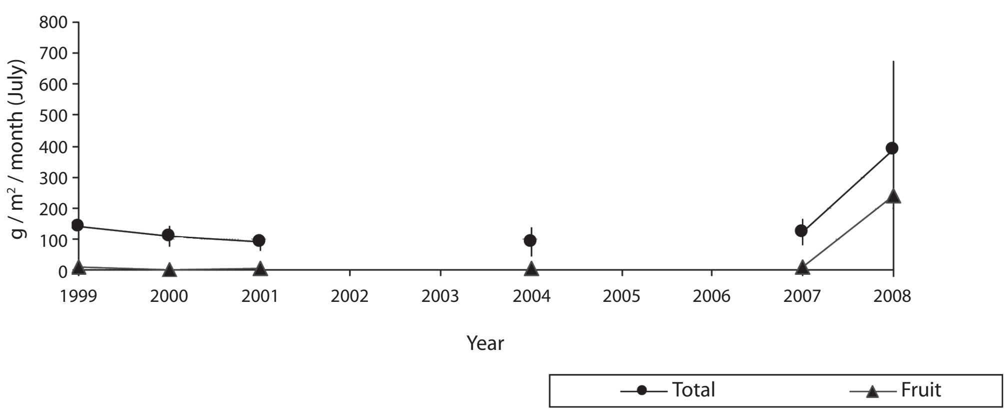

Fig. 16. Mangrove (*Rhizophora mangle*) mean (±standard deviation) productivity in July at Gandoca (REGAMA), 1999 to 2008.

prep.). Although the proportion of diseased colonies decreased by 14%, live coral and coralline algae cover are low, while non-coralline and turf algae dominated the substrate and have increased. Since the decline in live coral cover, from 40% in the late 1970's to 11% in the early 1990's (Cortés 1994), in the last four years it has remained relatively stable at around 18%. Suspended particulate matter continues to be the main source of stress and have increased between 1979 (9mg/l) and 1992 (~20mg/l) (Cortés 1994), reaching 24mg/l in 2005 (Roder 2005, Roder *et al*. 2009). It seems that live coral cover cannot increase due to the presence of these sediments, possibly affecting coral recruitment as well as the diversity of reef-building coral species that can grow under those conditions.

The sea urchin *D. antillarum*, a key herbivore species, was common in Cahuita (43 ind/10m^2; Cortés 1981) before the 1983 mass mortality in the Caribbean region (Lessios *et al*. 1984; Murillo & Cortés 1984). Since then, the density of *D. antillarum* decreased (0.01ind/10m^2, Cortés 1994) but seems to be recovering as densities are now higher than 10 years ago, with 0.1-1ind/10m^2 in shallower sites of Cahuita (Fonseca 2003, Alvarado *et al*. 2004) and 2-7ind/10m^2 from 2000 to 2008 in Meager Shoal. Additionally, several individuals were seen spawning in 2000 (Fonseca 2003). In the last eight years the densities of *E. viridis* decreased significantly (Fonseca *et al*. 2006 and Fig. 10). It has been observed at other coastal points that populations of *E. viridis* vary widely during the year apparently due to changes in algal density (J.J. Alvarado, pers. com. 2010).

Fish density was low perhaps as a result of the low relief of this reef (Phillips & Pérez-Cruet 1984) and has decreased from 20ind/100m^2 in 1999 (Fonseca & Gamboa 2003), to approximately 17.3ind/100m^2 in 2007, with lower densities in 2005 and 2006 (Table 1). Fish diversity and density is lower in Cahuita (Fonseca & Gamboa 2003, this study) relative to other Caribbean reef areas (49ind/100m^2, Ginsburg & Lang 2003), possibly related to the poor condition of the coral reef. Fishing pressure was comparatively low as only line fishing was allowed inside the park (Fonseca & Gamboa 2003). Fish declines have also been observed in other Caribbean reefs (Paddack *et al*. 2009).

Comparing our data for 2000 with data published for other CARICOMP sites in the wider Caribbean for that same year (CARICOMP 2002, Linton & Fisher 2004), live coral cover was low (14.5%) but not the lowest, as cover ranged from 1.1% in Puerto Morelos, Mexico, to 44.8% in La Parguera, Puerto Rico and was similar to coral cover at Carrie Bow Cay, Belize, and Discovery Bay, Jamaica (both 12.1%). Live coral cover has been low (<50%) at all CARICOMP sites since the 1980's. On the other hand algae cover was intermediate (62.9%) compared to the CARICOMP range (0.1% in Cayo Sombrero, Venezuela and 92.8% in Puerto Morelos, Mexico) and was also similar to Carrie Bow Cay (53.7%) and Discovery Bay (56.1%). The density of *D. antillarum* (5 ind/10m^2) was low, compared to the maximum density found in Barbados (19.4 ind/10m^2) yet similar to other CARICOMP sites like Jamaica. The populations of *E. viridis* were also low. Algal biomass is also considered to be low, because turf is the dominant form in Meager Shoal (Fonseca *et al*. 2006). The coral reef at PNC, as other CARICOMP sites, does not show a strong recovery since the 1980's.

Seagrasses

Seasonal differences in *T. testudinum* density, biomass and primary production, with maximum values in the summer and minimum values in winter, have been reported by Zieman (1974a, b, 1975), Thorhaug and Roesler (1977) and Van Tussenbroek (1995) for sites in the United States and Mexico. Leaf production reaches peak levels from May to July, in the Gulf of Mexico (Van Tussenbroek 1995), which coincides with the peak of productivity and turnover rate found in June in this study. Kaldy & Dunton (2000), found that seasonal fluctuations are the dominant controls on growth and production of *T. testudinum* in a subtropical coastal lagoon (Lower Laguna Madre, Texas). The more stable light and temperature conditions in tropical regions are reflected in a generally more uniform biomass throughout the year (Duarte 1989, Hillman *et al*. 1989). However, considerable seasonal biomass fluctuations have been observed in the tropics. Moderate changes in daily light period and temperature in some cases partially explain such observations (Mellors *et al*. 1993, Lanyon & Marsh 1995).

Fonseca *et al*. (2007a) reported a decrease in seagrass productivity and biomass between 1999 and 2005. A further decrease was observed in 2006, but then an increase in 2007 and 2008. There is an overall decreasing trend, yet no significant correlation with temperature increase was found. Furthermore, turnover rate and temperature were also not correlated. However, leaf growth, biomass and primary production were found to be inversely correlated with water temperature in a Mexican Caribbean coral reef lagoon (Van Tussenbroek 1995). Plants run the risk of experiencing thermal stress, which can be detrimental and result in plant death (Zieman & Wood 1975). The major influence of temperature on seagrasses is physiological, relating to the individual species thermal tolerances and their optimum temperatures for photosynthesis, respiration and growth (Short *et al*. 2001). Light, temperature, and inorganic nutrients affect biochemical processes of organisms and are considered as a major factor controlling seagrass growth. Lower leaf biomass and size are early plant responses to light reduction (Lee & Dunton 1977, Lee *et al*. 2007).

Between March and April of 1995 (Cortés 1998), at another seagrass site in the lagoon in front of Cahuita Point, *Thalassia* density was 1035±38 shoots/m^2 and its productivity was 3.0±3.20g/m^2/day using the CARICOMP protocol. In 1999, (March-April), a density of 1418 shoots/m^2 and a productivity of 2.4 g/m^2/day were recorded at Perezoso (Paynter *et al*. 2001), while Fonseca *et al*. (2007a) report values of 1184±335 shoots/m^2 and 2.7±1.2g/m^2/d respectively. This study reported a mean density of 1079±250 shoots/m^2 and productivity 1.6±0.7g/m^2/d. At Perezoso, the density, abundance and frequency of *T. testudinum*, showed peaks in January, May and September. The abundance of *T. testudinum* was highest in July, the rainiest month (Nielsen-Muñoz 2007).

Total above and below ground biomass was highest (>4 000g/m^2) in Belize, lowest in Tobago and Curacao (200-500g/m^2), and intermediate to high (750-1 500g/m^2) at all other CARICOMP sites (Colombia, Cuba, Mexico, Puerto Rico and Venezuela), including Costa Rica (978.6±281.6 g/m^2, n=42). Intermediate biomass of *Thalassia testudinum* in Costa Rica could be attributed to greater abundance of epiphytes on their leaves as reported for Mochima Bay, Venezuela (Díaz-Díaz & Liñero-Arana 2007). Productivity in the Caribbean varies from <0.5g/m^2/d (Bahamas) to >5g/m^2/d (Venezuela) and turnover rates average 3.9%/d. In Costa Rica, productivity (1.6±0.7g/m^2/d, n=74) is also intermediate, compared to other sites, and similar to that found in Colombia. Turnover rates are high (4.4±1.2%, n=74) compared to what was found in March and August at other sites. Similar values were found between March and June in Barbados, México, Bermudas and Puerto Rico (Linton & Fisher 2004). Turnover rates are probably higher in seagrass beds growing along the shorelines of continents or big islands subjected to a higher discharge of terrestrial nutrients, which makes them more vigorous. Shoot densities average 725shoots/m^2 in the Caribbean region but in Costa Rica are higher (1079±250.0shoots/m^2) perhaps due to the sampling sites being in a protected area. Average leaf length and width in the entire region were 14.4cm and 10.6mm, respectively, which are higher than in Costa Rica (9.2cm and 7.9mm respectively). The average leaf area index for the Caribbean sites is 3.4, while it is 2.4 in Costa Rica (CARICOMP 1997b, Creed *et al*. 2003, Linton & Fisher 2004).

Since the seagrass beds in Cahuita are found adjacent to the fringing coral reef, they are in close interaction and serve as nursery and feeding ground for reef organisms. Recreational boating, swimmers and nutrient loading from deforested lands in the coast, the upstream rivers and local pollution (Roder 2005, Roder *et al*. 2009) are all potential sources of impact to seagrass cover and productivity and therefore to the fishing activity of the coastal community (Creed *et al*. 2003). These interaction need to be evaluated in the near future. Furthermore, establishing the habitat requirements of each seagrass species and evaluating their particular response to water quality and sediment types is also needed.

Mangrove

The peak of productivity and flower production of *R. mangle* in Costa Rica were in July. Mangrove productivity decreased since 2001, and water temperature seems to have decreased; however, more sampling is needed to determine if they are correlated. The productivity trend for CARICOMP sites was clearly related to temperature, and also appears to be affected by rainfall, yet a more extensive data set will be necessary to evaluate this relationship.

Only Pool *et al*. (1977) have published on Caribbean coast mangroves of Costa Rica, and this was at Moín. However, it is important to note that the Moín mangrove is riverine and the dominant species was *Pterocarpus officinales*, differing from Gandoca. The mean basal area of all trees at Moín was higher (96.5 m^2/ha; Pool *et al*. 1977), than Gandoca (22.91±9.14m^2/ha), because there the mangrove is lagoonar and dominated by *R. mangle*.

Mean mangrove tree height found in the Caribbean coast of Costa Rica is similar to that of the Pacific coast; however, basal area was in some cases lower in the Caribbean than in the Pacific (Jiménez & Soto 1985, Jiménez 1988, 1994). Similarities in forest structure are found between the Caribbean and the Pacific when they have similar Holdridge climatic complexity indices (Jiménez & Soto 1985). However these observations are not conclusive (Fonseca *et al*. 2007b) since studies from the Pacific (Jiménez 1994) include other mangrove species besides *R. mangle*.

Biomass at eleven CARICOMP sites in 1995, measured using the Cintron and Schaeffer-Novelli (1984) equation, varied from about 1 kg/m^2 in Bahamas and Carry Bow Cay, Belize, to 19kg/m^2 in Colombia and Venezuela; while the number of trees per plot (10x10m) varied from 9 in Venezuela to 87 in Dominican Republic (CARICOMP 1997c). Therefore biomass in Costa Rica (14kg/m^2) was intermediate, while density (9 trees/plot) was relatively low. Biomass was similar to Bermuda (12kg/m^2) and its density the same as that found in Venezuela (9 trees/plot). Yearly productivity ranged from about 1g/m^2/day in Bahamas and Bermuda, to 10g/m^2/day in Venezuela. The productivity found for July in Costa Rica (5g/m^2/day) is similar to that found for most reported CARICOMP sites as Cayman, Trinidad and Bermuda in that same month (in all cases the month with the highest temperature); yet lower from that found in Venezuela. In Venezuela and Cayman, as in Costa Rica, July was the most productive month of the year. The highest published estimates for above-ground biomass of *Rhizophora* dominated mangroves stands in Asia and the Pacific were over 70kg/m^2, and average productivity 3g/m^2/day (Clough 1992), therefore, most of the CARICOMP biomass data, including Costa Rica, fall within the lower half of the biomass range and the productivity approaches the global litter fall average.

Mangroves act as exporters of nutrients and sediment traps, and there is no doubt that their removal adversely affects coastal water quality (CARICOMP 1997c). The Gandoca mangrove tripled its area from 1976 to 2000, due mainly to sedimentation processes originated by runoff from the river catchment, since most of the growth was toward the lagoon, and to sea level rise caused by sinking of the lagoon during the April 1991 earthquake, with some new mangrove inland (Denyer 1998, Coll *et al*. 2001). Apart from a flood that washed away some trees, this mangrove seems to have very little impact from the local community, which is rather small (Coll *et al*. 2001); logging is not systematic, and locals are shifting their agricultural practices to ecotourism in the area of the lagoon. Levels of pesticide pollution were very low (Coll *et al*. 2004). Environmental awareness of the inhabitants of Gandoca and the protected status of this mangrove by the Gandoca Manzanillo National Wildlife Refuge might guarantee the mangrove´s survival, expansion and functionality, as well as better quality of life for the Gandoca inhabitants. It is recommended to keep updating information on mangrove cover at Gandoca and search deeper into the causes of this beneficial expansion.

CONCLUSIONS

- Coral reefs at Cahuita National Park continue to be impacted by terrigenous sediments.
- Compared to other CARICOMP sites, live coral cover, fish diversity and density, and sea urchin density were low, while algal cover was intermediate. Seagrass productivity, biomass, average leaf length and width were intermediate, and seagrass turnover rates, shoot density and leaf area index were rather high. Mangrove biomass and density were relatively low, while productivity was intermediate.
- Management actions, mainly inland, should be considered in order to protect and preserve these important coastal ecosystems. The recovery of forest cover, especially riverine forests, in the watersheds must be a priority to reduce sediments loads that reach the coral reefs.

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RESUMEN

Los arrecifes coralinos, pastos marinos y manglares de la costa Caribe de Costa Rica han sido monitoreados desde 1999 siguiendo el protocolo de CARICOMP. La cobertura de coral vivo en el arrecife de Meager Shoal (7 a 10m de profundidad) en el Parque Nacional Cahuita, aumentó de 13.3% en 1999, a 28.2% en 2003, pero después bajó, por los siguientes 5 años, a aproximadamente 17.5%; la cobertura de algas aumentó significativamente de 36.6% en 2003 a 61.3% en 2008. La densidad de *Diadema antillarum* osciló entre 2 y 7 ind/m^2 mientras que *Echinometra viridis* decreció significativamente de 20 a 0.6 ind/m^2. Comparado con otros sitios CARICOMP, la cobertura de coral vivo, diversidad y densidad de peces, y densidades de erizos de mar fueron bajas y la cobertura algal intermedia. El sitio de pastos marinos, también en el Parque Nacional Cahuita, está dominado por *Thalassia testudinum* y tiene una productividad (2.7±1.15g/m^2/d) y biomasa (822.8±391.84g/m^2) intermedia comparado a otros sitios CARICOMP. Los arrecifes coralinos y pastos marinos en el Parque Nacional Cahuita continúan siendo impactados por sedimentos terrígenos. El bosque de manglar en Laguna Gandoca, dentro del Refugio Nacional de Vida Silvestre Gandoca-Manzanillo, está bordeado por una laguna y predomina el mangle rojo, *Rhizophora mangle*. El pico de productividad y producción de flores fue en julio. La biomasa (14 kg/m^2) y densidad (9.0±0.58 árboles/100 m^2) en Gandoca fueron relativamente bajas comparadas con otros sitios CARICOMP, mientras que la productividad en julio en Costa Rica (4g/m^2/d) fue intermedia, similar a la mayoría de los sitios CARICOMP. Este manglar se está expandiendo y tiene muy poco impacto humano hasta ahora. Se deben tomar acciones de manejo para proteger y preservar estos importantes ecosistemas costeros.

Palabras claves: Cahuita, Gandoca, Caribe, Costa Rica, cobertura de coral, productividad, *Thalassia testudinum*, *Rhizophora mangle*, *Diadema antillarum*, floración de *Thalassia*, CARICOMP.

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