Cah. Biol. Mar. (2007) 48 : 113-119

Recruitment and juvenile survivorship of brain corals at San Andres Island, Western Caribbean Sea

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Abstract: Recruitment and juvenile survivorship can affect population dynamics and resilience. In this paper we present data on brain coral (genera *Diploria* and *Colpophyllia*) recruitment and recruit cohort survivorship obtained at three stations in 2001 at San Andres Island (Colombia) as part of the baseline used to develop a Marine Protected Area (MPA) system. Two stations were on the leeward and one on the windward side of the island. Monthly recruitment and cohort survival were measured on PVC panels deployed monthly. Recruitment was significantly lower (ANOVA) on the upper sides of the panels, and started in June until November and with a peak in June at the deepest (20-25 m) leeward station. Cohort survivorship did not vary between stations but Kaplan-Meier survival curve showed higher initial survival. The brain coral recruitment rates are the highest recorded for the Caribbean. We strongly recommend continuing conservation efforts to assist the persistence of these populations.

Résumé : *Recrutement et survie des juvéniles d'espèces de corail cerveau sur l'Ile de San Andres, Mer Caraïbe occidentale.* Chez les coraux, le recrutement et la survie des juvéniles sont des facteurs affectant la dynamique des populations ainsi que sa résilience à l'extinction. Nos travaux portent sur les taux de survie des cohortes et de recrutement d'espèces de corail cerveau (*Diploria* sp. et *Colpophyllia* sp.), ces données ont été obtenues pendant la mise en place d'une Aire Marine Protégé (AMP) dans l'ouest des Caraïbes. Trois stations d'échantillonnage ont été établies, deux au vent et une sous le vent. Le recrutement et la survie des cohortes ont été mesurés dans des panneaux de PVC déployés chaque mois. Le recrutement, significativement réduit dans la partie haute des panneaux (ANOVA), s'est étalé de juin jusqu'à novembre avec un maximum en juin au plus profond (20-25 m) dans la station sous le vent. La survie des cohortes n'a pas varié entre les différentes stations, toutefois la courbe de survie de Kaplan-Meier suggère une survie plus importante au cours des premiers mois. Les taux de recrutement enregistrés sont les plus hauts des caraïbes. Nous recommandons fortement de poursuivre les efforts de conservation pour assurer la persistance de ces populations.

Keywords: Brain coral • *Diploria* • *Colpophyllia* • Marine protected area • Recruitment • Survivorship • Caribbean Sea

Reçu le 9 mars 2006 ; accepté après révision le 2 mars 2007.
Received 9 March 2006; accepted in revised form 2 March 2007.

Introduction

It was long assumed that only after settlement of the larva did selection play an active role in coral population dynamics (see Harrison & Wallace, 1990). It is now known that selection starts from the moment that propagules are released into the water column (Mumby, 1999). Even so, recruitment of larvae is one of the major steps in structuring coral communities (e.g. Olson, 1985; Roughgarden et al., 1985; Harrison & Wallace, 1990). In this paper we differentiate between settlement which we define as the process of attachment of coral larvae to the substratum, whilst recruitment implies settler metamorphosis and is a measure of the influx of new individuals corals into a population (Müller & Leitz, 2002). Recruitment can be affected by biotic factors such as abundance of algae (Baird & Hughes, 1997), presence of other benthic invertebrates (Fabricius & Metzner, 2004), predation (Baird & Hughes, 2000) and abiotic factors such as light intensity (Babcock & Mundy, 1996) and sedimentation rate (Birrel et al., 2005). These factors interact to shift the larval preference for cryptic surfaces in shallow water to upwards facing surfaces in deeper water (e.g. Birkeland & Randall, 1981; Birkeland et al., 1981; Babcock & Mundy, 1996). The effects of these factors on recruitment may also be mediated by anthropogenic impacts which are primarily measured by the negative effects of pollutants on recruitment rates and survival (e.g. Koop et al., 2001; Negri et al., 2002; Birrel et al., 2005; Flood et al., 2005). Because the impact of a reduction in recruitment on future coral populations is poorly understood, it is crucial to study recruitment at reefs with different degrees of perturbation.

Some of the most common and important reef building corals in the Caribbean are brain corals (Bassim et al., 2002). The term brain coral includes all species in the genera *Diploria* and *Colpophyllia*. In the San Andres-Old Providence-Santa Catalina Archipelago (Colombia, Western Caribbean), brain corals are particularly abundant (Geister, 2001) although their numbers have decreased in the last few decades (Garzón-Ferreira et al., 2001). This has been attributed to anthropogenic impacts (Díaz et al., 1996) which are considered to be the major threat to San Andres' reefs.

After the Archipelago was declared a Biosphere Reserve by UNESCO in 2000, the local government decided to implement a marine protected area (MPA) system. Research was initiated to underpin this MPA and the results presented here complement the information gathered for the MPA baseline. This study aimed to determine recruitment rates and juvenile survivorship of brain corals at three stations; two located on the leeward reefs and one on the windward reef of San Andres Island. The importance of studying both processes (recruitment success and juvenile survivorship) is because of their central role in the recovery and maintenance of coral communities (e. g. Vermeij, 2006), and because this information facilitates the decisions for coral conservation and management (e.g. Dunstan & Johnson, 1998).

Methods

Three stations (Fig. 1), two on the leeward and one on the windward reefs, were established at San Andres Island (12º32'N, 81º42'W; western Caribbean, Fig. 1). Coral reefs are widespread around the island and reef formations are particularly complex as a result of heavy wave action and turbulence. For a more detailed description of the Archipelago's marine ecosystems see Díaz et al. (1996).

The location of the stations was determined by the demarcation of the MPA system. The shallowest station was at Little Reef (LR; 12º35'06''N, 81º41'13''W) which is located at the northeast side of the island (windward), inside the reef lagoon. It is an internal barrier reef 1 km long, ranging from 0.5 to 5 m deep. Two deeper stations were located on the leeward side of the island. The medium depth station (10-14 m) was at Piscinita Somero (PS; 12º30'29''N, 81º43'56''W) and the deepest (20-25 m) at Piscinita Profundo (PP; 12º30'29''N, 81º43'59''W). Live coral cover varied between stations (PP ~ 30%, PS ~ 20% and LR ~ 10%; Pizarro, 2002b).

Recruitment was monitored on black PVC panels (10 cm x 15 cm x 3 mm). Prior to deployment the panels were sandpapered to increase their rugosity (Zea, 1993; Pizarro, 2002a) and immersed on a local reef for a week at 1 m depth. Before final deployment, each panel was checked to ensure no coral recruits were already present. Two racks each holding eight panels were deployed at each site. One of the racks was used to obtain monthly recruitment rate, and the other was used to follow recruit cohort survival. Panels used to determine monthly recruitment rates were removed and replaced every month, whilst the other panels were left in situ for the duration of the study to follow cohort survivorship. The first racks were deployed during the first week of February 2001 and the last deployed in September 2001 (no panels were replaced or checked in October due to bad weather). Observations finished after nine months in November 2001. Due to the size of the coral planulae, panels can be considered true replicates (Maida et al., 2001).

Recruitment panels were transported to the laboratory and observed under a dissecting microscope (Olympus SZ40, optical lenses GSWH 10x/22x) and the number of brain coral (genera Diploria and Colpophyllia) recruits recorded. Records were made of both sides of each panel (upper or lower) and the status (dead or alive) of each recruit was also recorded. No recruits were found on the

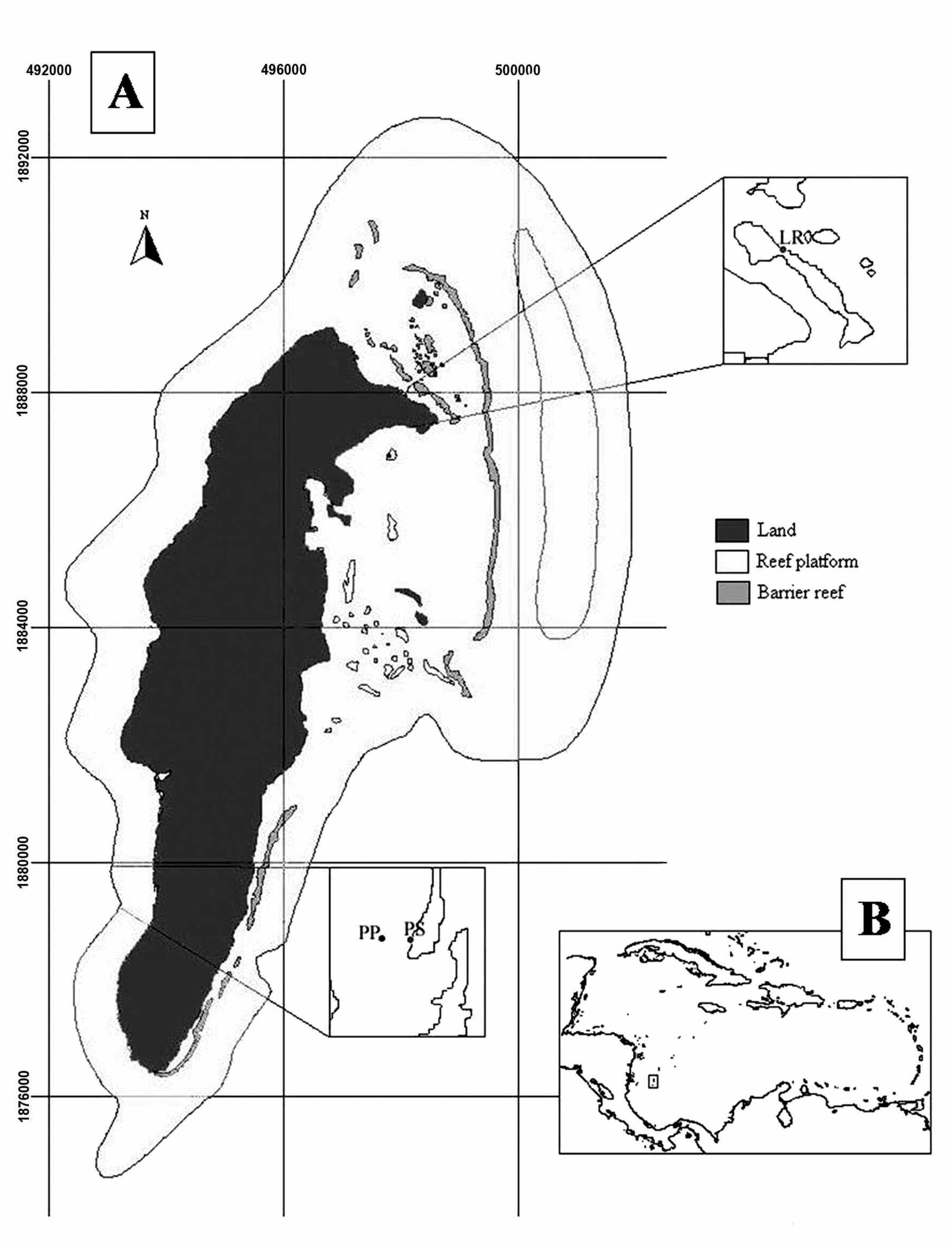

Figure 1. A. San Andres Island, the location of the stations: Little Reef (LR), Piscinita Profundo (PP) and Piscinita Somero (PS). **B.** Location of San Andres in Caribbean Sea.

Figure 1. A. Île de San Andres, localisation des différentes stations d'échantillonnage : Little Reef (LR), Piscinita Profundo (PP) et Piscinita Somero (PS). **B.** Localisation de San Andres dans la mer des Caraïbes.

edges of the thin panels. Cohort survival panels were checked monthly underwater using SCUBA and a 10x magnifying glass to record in situ monthly recruitment and survivorship.

Differences in recruitment rates and recruit mortality observed on the recruitment panels were compared by GLM ANOVA using a fully-factorial model with type III sums of squares. For recruitment rates, month and panel side were set as fixed factors, station as a random factor and fifth-root transformed numbers of recruits as the response. There were no significant three-way interactions and the reduced model with only two-way interactions is reported herein. For analysis of recruit mortality data, month was the fixed factor, station the random factor and arcsin square root transformed mortality was the response. Panel side was left out of the analysis due to the paucity of data. There were no significant two-way interactions and the reduced model with only main effects is reported herein. Plots of estimated transformed marginal means were generated to help interpret the results and the residuals were checked to ensure adequacy of both models. Cohort survival rates were analysed using Kaplan-Meier survival analysis (Blossfeld & Rohwer, 2002) with time to event (death) recorded in days and with station as the single factor. With this method it is possible to estimate the proportion of coral planulae surviving for any given time, which is also the estimated probability of survival to that time for a recruit of the population from which the sample is drawn. For each time interval is possible to estimate the probability that recruits who have survived to the beginning will survive to the end (Blossfeld & Rohwer, 2002). All statistics were performed in SPSS v12. It is important to note that it is possible that with the cohort survival method we missed some recently recruited corals, due to the resolution of the magnifying glass.

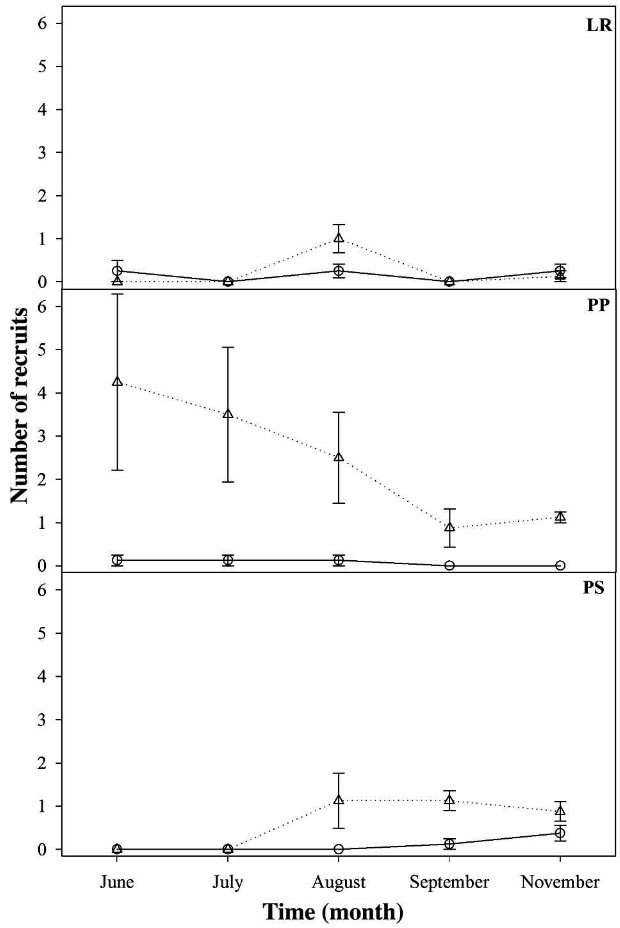

Figure 2. Number of recruits recorded on upper (o) and lower surfaces (Δ) of recruitment panels at each station for each month. Data shown are mean number of recruits panel^{-1} ± SD. (Little Reef - LR, Piscinita Profundo - PP and Piscinita Somero - PS).

Figure 2. Nombre des recrues enregistrées sur les surfaces externes (o) et internes (Δ) des plaques de recrutement à chaque station pour chaque mois. Les données présentées sont le nombre moyen (± écart-type) des recrues par plaque (Little Reef - LR, Piscinita Profundo - PP et Piscinita Somero - PS).

Results

Brain coral recruits were first observed on the tiles retrieved in July 2001 and new recruits were found from then until the end of the study in November 2001. In the laboratory a total of 145 brain coral recruits were counted (~ 38% were dead). In general the highest recruitment occurred at the leeward stations (PP: 0.13 recruits panel^{-1} ± 2.82 SE and PS: 0.36 recruits panel^{-1} ± 0.78 SE) compared with windward station LR (0.19 recruits panel^{-1} ± 0.51 SE; Fig. 2), though the analysis showed a more complex pattern with significant two-way interactions between both panel side x stations as well as between month x station (Table 1, Fig. 2). Recruitment was lowest on the upper surfaces of the panels at all sites (0.11 recruits panel^{-1} ± 0.34 SE), but varied between sites on the lower surfaces, with PP (2.45 recruits panel^{-1} ± 3.62 SE) having overall more recruits on the lower surfaces than PS (0.63 recruits panel^{-1} ± 1.00 SE) and LR having the least (0.23 recruits panel^{-1} ± 0.58 SE; Fig. 2).

The highest recruitment was at station PP in June (2.19 recruits panel^{-1} ± 4.5 SE) with fewest recruits at this station in September (0.44 recruits panel^{-1} ± 0.96 SE). PS showed highest recruitment in September (0.63 recruits panel^{-1} ± 0.72 SE) and November (0.63 recruits panel^{-1} ± 0.62 SE), with no recruits recorded in June and July. Station LR showed maximal recruitment peak in August (0.63 recruits panel^{-1} ± 0.81 SE) with no recruitment at all in July and September (Fig. 2).

Table 1. Results of the GLM analysis of recruits panel^{-1} with month and panel surface as fixed factors and station a random factor. Shown are type III sum of squares (SS), degrees of freedom (df), mean squares (MS), variance ratio (F) and probability (P) with significant results ($p < 0.05$) in bold. No three-way interactions were significant.

Tableau 1. Les résultats de l'analyse de GLM des recrues par plaque, le mois et la surface de la plaque en tant que facteurs fixes et la station d'échantillonnage comme facteur aléatoire. La somme des carrés de type III (SS), degrés de liberté (DF), carrés moyens (MS), rapport des variances (F) et probabilité (P) (p < 0,05 en gras). Aucune des interactions à trois facteurs n'étaient statistiquement significatives.

Source	SS	df	MS	F	P
Intercept	17.42	1.00	17.42	13.44	0.07
Month	2.86	4.00	0.71	1.12	0.41
Panel surface	6.79	1.00	6.79	3.57	0.20
Station	2.59	2.00	1.30	0.55	0.63
Month x Panel surface	1.02	4.00	0.25	1.55	0.19
Month x Station	5.11	8.00	0.64	3.89	**< 0.001**
Panel surface x Station	3.80	2.00	1.90	11.57	**< 0.001**

Recruit mortality varied significantly between stations (ANOVA, SS = 3.188, $F_{2,50} = 3.84$, P = 0.025). The highest mortality occurred at LR (72.7% ± 46.7 SE), with much lower mortality at both PS (25.0% ± 41.4 SE) and PP (24.0% ± 36.6 SE). A LSD test of the effect of station using the estimated marginal means with no adjustment of the family-wise error-rate revealed significant differences between LR and PP (P = 0.010) and LR and PS (P = 0.024), but not between PS and PP (P = 0.87). There was no significant main effect of month (F = 0.39, P = 0.82).

A total of 83 brain coral recruits were followed for cohort survivorship. There was no significant difference (P > 0.05) in recruit survival time between stations with mean survival ranging between 146.9 d ± 4.3 SE, 133.9 d ± 5.4 SE, 127.8 d ± 12.4 SE for stations PS, PP and LR, respectively. Nevertheless, the shape of the survival curves suggest that survivorship at LR being initially much higher that for PS and PP and then dropping quickly during the last months of the study (Fig. 3).

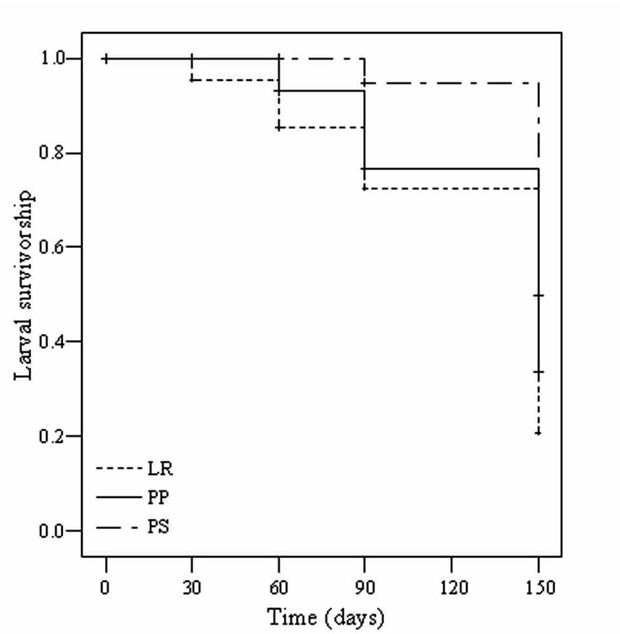

Figure 3. Survivorship of brain coral recruits at Little Reef (LR), Piscinita Profundo (PP) and Piscinita Somero (PS). Curves generated using Kaplan-Meier procedure in SPSS.

Figure 3. Survie des recrues de corail cerveau à Little Reef (LR), Piscinita Profundo (PP) et Piscinita Somero (PS). Courbes générées selon la méthode de Kaplan-Meier dans SPSS.

Discussion

Recruitment of the brain coral genera *Diploria* and *Colpophyllia* at San Andres is the highest recorded for the Caribbean. Rogers et al. (1984) observed only 3 brain coral recruits during a 26 month study at St. Croix, and Smith (1992) found that annual brain coral recruitment in Bermuda was 19 x 10^{-6} recruits cm^{-2}. This is an order of magnitude lower than at San Andres (18 x 10^{-5} recruits cm^{-2}). Although this value is high for Caribbean coral reefs, it is low if compared to Indo-Pacific reefs (e. g. Harriott & Simpson, 1997). However due to the differences between these regions, for this paper comparisons are made only between other Caribbean studies. Further information on the differences between can be found in Richmond & Hunte (1990). The high rates of recruitment observed at San Andres could be a result of high fecundity and high survival at the time of the study. Long term research on coral recruitment is necessary to establish the viability of those recruits, therefore of the San Andres' brain coral populations. The effects of either prevailing wind and localized anthropogenic impact can be seen when comparing stations PP and PS with LR. The latter station shows low recruitment and the highest mortality rates. Conservation strategies have to be developed for LR in order to reduce mortality. Furthermore, given the large existing local populations compared within Caribbean reefs and the high recruitment then San Andres may be acting as a large source for reefs within the Archipelago and across the Western Caribbean. Further work on larval transport and larval competence is required to validate this hypothesis.

Recruitment patterns were similar to those reported elsewhere (e.g. Rogers et al., 1984; Wallace, 1985) with a general increase with depth and a peak at intermediate depths (Fig 2). Around San Andres island coral diversity is greatest at intermediate depths (~ 10-20 m; pers. obs.) where light availability becomes a limiting factor for algal growth (Birkeland et al., 1981). At all stations, filamentous algae were present on the upper sides of the panels (see also Díaz-Castañeda & Almeda-Jauregui, 1999). These algae act as sediment traps and consequently reduces coral recruitment (Birkeland et al., 1981; Wittenberg & Hunte, 1992). A preference by the larvae to recruit on alga- and sediment-free surfaces (Birrel et al., 2005) can explain the higher recruitment on the lower sides of the panels at all stations.

Although the abundance of filamentous algae may affect recruitment at the windward station (LR), this station is also affected by a complex combination of other important factors. Station LR is exposed to medium-high water movement, impacted by oil spilt by tourism boats, and subject to both over-fishing and minor scale terrestrial run-off (Díaz et al., 1995) which may have a detrimental effect on coral recruitment and survivorship (e.g. Gilmour, 1999; Negri & Heyward, 2000; Koop et al., 2001; Fabricius et al., 2003; Birrel et al., 2005). There is also evidence that the reef community structure at this site has changed considerably during the last three decades largely due to the effects of the Caribbean-wide Diadema antillarum mass mortality (see Lessios, 1988), which has resulted in a macro-algae dominated reef (Díaz et al., 1995).

Several questions raised from this study: could actual brain coral populations be maintained by coral recruitment? Are brain coral planulae from local populations or from coral populations near or far from San Andres? Are San Andres reefs acting as a sink area for brain coral planulae? To answer these questions further research is necessary. We strongly recommend all the agencies of the Archipelago to develop a long-term research study to increase the knowledge on coral population dynamics. The creation of the UNESCO Biosphere Reserve and MPA system may be crucial for the maintenance and conservation not only of brain coral populations but of all the species that co-exist in the coral reefs.

Acknowledgments

The National University of Colombia, through the Institute of Caribbean Studies, made this study possible. The authors want to thank all the people that worked and supported this project in any way, especially Martha Novoa. JC Thomason is supported by The Royal Society.

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