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NOTE

Spatial and size-frequency distribution of *Acropora* (Cnidaria: Scleractinia) species in Chinchorro Bank, Mexican Caribbean: implications for management

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Abstract The Mexican Government decreed Chinchorro Bank reef as a Biosphere Reserve in 1996. The aim of this study was to evaluate the spatial and size-frequency distribution of *Acropora* spp. in order to provide further knowledge and tools to enhance management. A field survey was conducted, within six regions, to locate and measure *Acropora* patches in the reef lagoon. Density, colony size and living tissue cover of *Acropora* colonies were evaluated using the line-intercept transect technique, combining direct observations and video transects. The results showed that *Acropora* spp. was preferentially distributed in the southern regions; where cover and density were high. Based on these results and considering that *Acropora* spp. produces landscape heterogeneity, which in turn generates shelter for other species, including some of considerable economic importance, then at least the South East region should be considered as a key area for *Acropora* species conservation, and should be included in the Chinchorro Bank management plan.

Keywords Biosphere Reserve · Corals · Core areas · Coral reefs · Fisheries · Marine protected areas

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Introduction

The geographical distribution of *Acropora* spp. in the Greater Caribbean includes the Bahamas, Florida, Mexico, Central America and the Antilles (Wallace 1999; Veron 2000; Vargas-Ángel et al. 2003). *Acropora palmata* is predominantly found in shallow water (0–5 m), is the main reef-building coral species on the reef flat, and dominates the back reef (Jackson 1991; Aronson and Precht 2001a). The distribution of *Acropora cervicornis* ranges from <1 to 25 m depth (Jackson 1991; Aronson et al. 2002), and also occurs in the back reef and lagoon habitats (Geister 1977). The hybrid, *Acropora prolifera*, is rare (Lang et al. 1998), and predominantly found between 0.5 and 2 m depth (Pral and Erhardt 1985). In the Caribbean, degradation of *Acropora* spp. populations is caused by several factors such as coral diseases (e.g., white band disease caused mortality in the 1980s and early 1990s), hurricanes, hypothermic stress, physical damage caused by boats and other anthropogenic activities such as fishing, scuba diving and anchoring (Bythell et al. 2000; Bruckner and Bruckner 2001). Thus, *A. palmata* and *A. cervicornis* are under special protection by the Mexican ecological law (Norma Oficial Mexicana NOM-059–ECOL-2001 2002), and the National Marine Fisheries Service added both species to the threatened species list (Federal Register 2006).

The Mexican Government decreed Chinchorro Bank as a Biosphere Reserve in 1996. This reef has been an important fishing ground for spiny lobster *Panulirus argus* and queen conch *Strombus gigas* (Sosa-Cordero et al. 1993). Chávez and Hidalgo (1987) characterized the fisheries impact as chronic and as the only anthropogenic threat. Sosa-Cordero (1994) observed that the depletion of both *P. argus* and *S. gigas* populations was evident in Chinchorro Bank as a consequence of the fisheries impact (Carricart-Ganivet and Beltrán-Torres 1998). Chávez et al. (1985) briefly described the coral community structure, and Jordán and Martin (1987) described the morphology and reef assemblage structure of Chinchorro Bank. To our knowledge, there are no published works related to *Acropora* spp. distribution in Chinchorro Bank, hence the aim of this work was to describe the spatial distribution, and partial mortality of *Acropora* spp. to provide the knowledge and tools for improved management of the genus at this important Caribbean atoll-like reef.

Materials and methods

Study area

Chinchorro Bank is located 27 km off the south-eastern coast of the Yucatán Peninsula (18°23′–18°47′N, 87°14′–87°27′W). It is an oval-shaped reef, 48 km long and 18 km in its widest part, with a lagoon area >500 km^2. It is separated from the mainland by a 1,000 m depth channel (Fig. 1). Jordán and Martin (1987) described the open reef lagoon as shallow, ranging from 7–9 m depth in the southern section to 2 m depth in the northern part, with patch reefs and coral knolls that decrease gradually in number and size from south to north. The reef has four islands: two in the north (both known as Cayo Norte), one in the center (Cayo Centro) and one in the south (Cayo Lobos).

Field methods

The field work was conducted in the reef lagoon, during 2002, in two stages. First, *Acropora* patches and colonies were located and their depth measured with a dive computer. An *Acropora* "patch" was defined as an aggregation of at least ten colonies with no more than 0.5 m between patches. Patches were located and the bottom type recorded, using the manta-tow search technique (Bass and Miller 1996) and the Geographic Information System of Chinchorro Bank of Carricart-Ganivet et al. (2002). The geographic position, of each *Acropora* patch and colony, was registered using a GPS Garmin XL12. Each patch was measured along the longest and widest axis to estimate its area as a rectangular polygon. Based on observed hydrodynamic characteristics, bottom type, and the Chinchorro Bank description of Jordán and Martin (1987), the reef lagoon was divided into six regions: Southwest (SW), Cayo Lobos (CL), Southeast (SE), Northwest (NW), Cayo Norte (CN) and Northeast (NE) (Fig. 1). All data were analysed with Arcview V. 3.3 Geographic Information System software to characterize the spatial distribution of *Acropora* species.

During the second stage, five pairs of 10 m length transects, 25 m from the breaker zone, were established

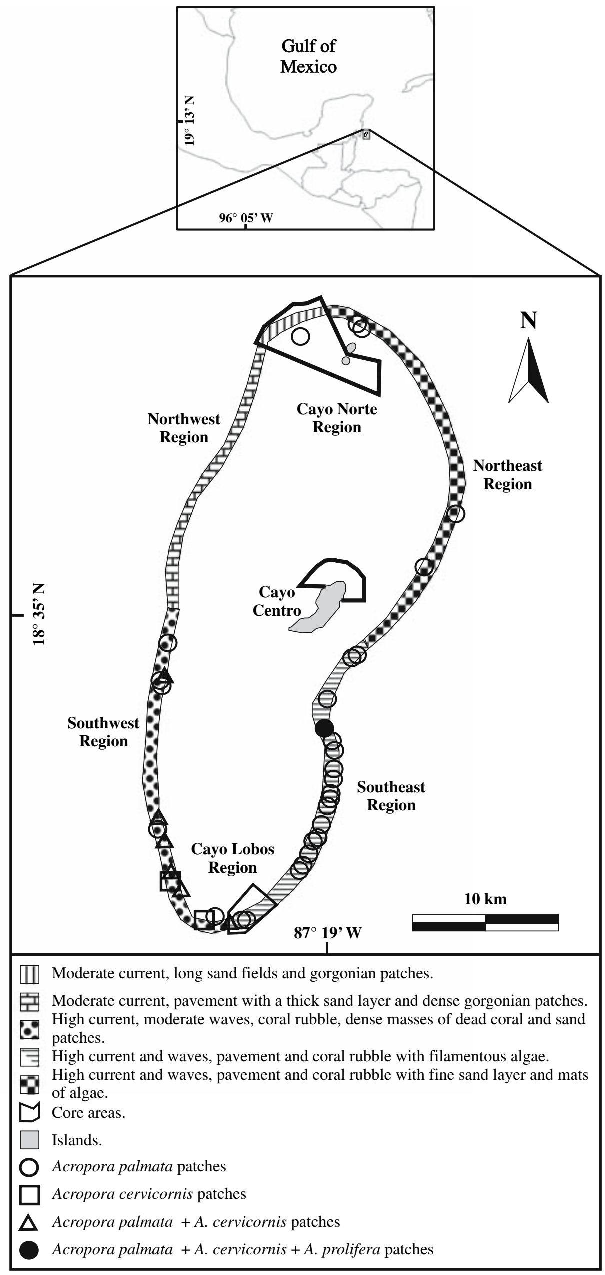

Fig. 1 Location of Chinchorro Bank showing the different sampled regions with their physical characteristics of bottom and currents and waves, and the location of the *Acropora* spp. patches recorded in this study

randomly along the back reef at each region. The distance between each transect was 20 m, and pairs of transects were placed ~500 m apart. Density, colony size (volume) and percent living tissue cover of *Acropora* colonies were evaluated.

Density was measured using the line-intercept transect technique (Loya 1972, 1976). Colony volume was calculated for each intersected *Acropora* colony, using the maximum length, width and height. An individual coral colony was defined as any autonomous, free-standing coral skeleton with living tissue (Bak and Meesters 1998). Since colony volume was calculated as if a colony was a solid body, which clearly it is not, the volume estimates are greatly overestimated. Nonetheless, for the purposes of this study, patterns emerging from these data are comparable among regions. Data on living coral tissue cover was collected using the video-transect methodology (Vogt 1995), following the line-intercept transect used for density and colony volume estimates (Dodge et al. 1982). Transects were recorded using a digital camcorder held perpendicular to the bottom along the sampling transect line, the distance to the substrate was controlled by a 50 cm line with a dead weight (Vogt 1995).

Twenty video-frames (0.45 m × 0.35 m each), separated by 0.5 m were analyzed per video-transect (3.15 m^2). Each video-frame was displayed on a high-resolution monitor. A clear plastic sheet divided in 1 cm^2 squares was laid over the monitor screen. The number of squares occupied by *Acropora* spp. living tissue (LT, cm^2) was counted and cover percentage (CP) estimated as: CP = (LT/1,575) × 100.

Results and discussion

Acropora spp. patches were distributed along Chinchorro Bank rim; with greatest patch abundance observed mainly in the back reef, and highest concentration found in CL, SE and SW regions (Fig. 1; Table 1). Patches of *A. palmata* were found in all regions, except the NW one, decreasing in size and number from south to north (Fig. 1; Table 1), coincident with an increasing predominance of sand and dense algal mats (Fig. 1). All *A. palmata* patches were supported on coral rubble and calcareous pavement, in turbulent or high energy localities, between 0.5 and 3.5 m depth. The largest patches were located in the SE region (Table 1), growing up from the wave-break zone into the reef lagoon, displaying a triangular shape (Fig. 2). The SE region is a highly exposed area, characterized by strong surface currents and large waves. In the Greater Caribbean reefs, *A. palmata* dominates shallow high-wave intensity areas, forming large and dense patches, since this species is adapted to tolerate physical stress (Goreau 1959; Rogers et al. 1982; Aronson and Precht 2001a; Pandolfi 2002). During storm events, the strength of the surface currents and wave intensity is likely to cause *A. palmata* fragmentation, which is the principal mechanism of asexual reproduction and dispersion of this species (Bak and Engel 1979; Bothwell 1981). Such frequent fragmentation is likely to be the cause of the triangular shape of *A. palmata* patches observed in this region of the bank (Fig. 2).

Acropora cervicornis patches were only located in the SW region (Fig. 1, Table 1), growing on sandy substrate, between 3 and 4 m depth, where currents and waves are relatively minimal (Jordán and Martin 1987). These conditions have been proposed as the main requirements for settlement and growth of *A. cervicornis* (Geister 1977; Aronson et. al. 2002). Multi-specific patches occurred only in the southern regions (Fig. 1, Table 1), between 0.5 and

Table 1 Number of patches per species and mean size by region

Species/region	Number of patches	Mean patch size (m^2)
Acropora palmata		
Southwest	9	356.0 (297.6)
Cayo Lobos	3	637.3 (104.4)
Southeast	14	848.1 (984.9)
Northwest	NR	NR
Cayo Norte	1	672.0
Northeast	4	165.3 (153.7)
Acropora cervicornis		
Southwest	8	28.9 (17.3)
Cayo Lobos	NR	NR
Southeast	NR	NR
Northwest	NR	NR
Cayo Norte	NR	NR
Northeast	NR	NR
Multi-specific		
Southwest	6[a]	351.5 (231.1)
Cayo Lobos	2[a]	120.1 (93.5)
Southeast	1[b]	1800.0
Northwest	NR	NR
Cayo Norte	NR	NR
Northeast	NR	NR

Standard deviations in parenthesis

NR no patch registered

Multi-specific patches: [a] *A. palmata* + *A. cervicornis*, [b] *A. palmata* + *A. cervicornis* + *A. prolifera*

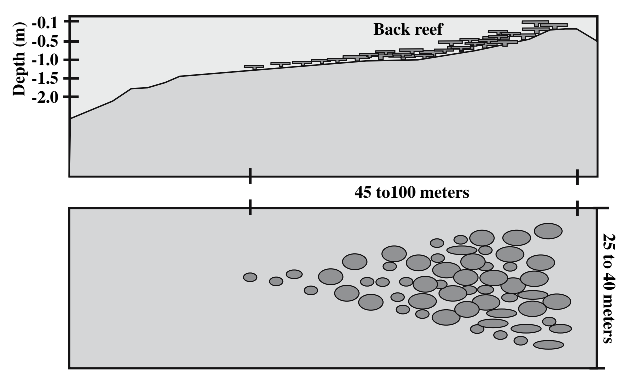

Fig. 2 *Acropora palmata* triangular shape patch in the Southeast Region

3.5 m depth. In the SW and Cayo Lobos regions the patches included both species; however, in the SE region the patches also included the hybrid *A. prolifera*, occurring as the two morphotypes described by Vollmer and Palumbi (2002): bushy and palmate. Goreau (1959) and Vollmer and Palumbi (2002) pointed out that this hybrid is rarely forms patches. An explanation of the presence of *A. cervicornis* and *A. prolifera* in the SE region could be the association with *A. palmata*, which provides wave protection. On the southern end of the bank *A. palmata* was observed at higher density and cover (Table 2) than *A. cervicornis*, which was present only in the SW and Cayo Lobos region, with very low densities; this being in agreement with the results of Jordán and Martin (1987). The frequency distribution of colony volume within the three southern regions (Fig. 3) shows that the SE region followed a nearly normal distribution (asymmetry of 0.04; Fig. 3a), thus this distribution may be a consequence of asexual fragmentation by wave impact. Loya (1976), Rogers et al. (1982), Hughes (1984) and Aronson and Precht (2001b) have pointed out that *Acropora* spp. susceptibility to fragmentation increases the colony's probability of survival. The fragmentation process, therefore, results in a broad range of sizes representing the full spectrum of volume size classes. On the other hand, the SW region had a skewed (asymmetric) distribution (−2.51; Fig. 3b), with a predominance of large colonies, suggesting that fragmentation is less frequent in the SE region. The Cayo Lobos region presented a positive asymmetry (i.e., more right skewed) (0.46; Fig. 3c) with a small deviation towards smaller colonies, suggesting either relatively recent colonization, or that there are other factors limiting survival, or even that fragmentation is exceedingly high.

Since *Acropora* spp. has special protection status in Mexican ecological law (Norma Oficial Mexicana NOM-059-ECOL-2001 2002), based on the distribution of patches, their density and percent living tissue cover measurements, the southern regions, especially the SE region,

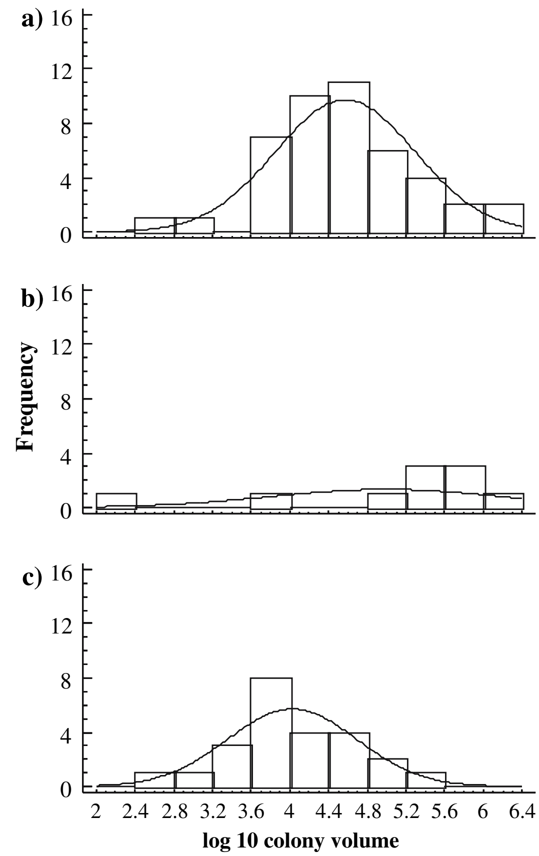

Fig. 3 Frequency distribution of colony volume of *Acropora palmata* in the **a** Southeast Region, **b** Southwest Region, and **c** Cayo Lobos Region

Table 2 Mean values of density, colony volume (cube root) and living tissue cover of *Acropora palmata* and *Acropora cervicornis* by region

Species/region	Density (colonies m^{-2})	Cube root of colony volume (cm)	Living tissue cover (%)
Acropora palmata			
Southwest	0.11 (0.14)	70.6 (73.1)	5.1 (9.0)
Cayo Lobos	0.25 (0.11)	32.5 (42.1)	5.4 (4.1)
Southeast	0.44 (0.24)	51.1 (63.7)	14.8 (6.7)
Northwest	NR	NR	NR
Cayo Norte	0.04 (0.10)	18.9 (17.5)	0.4 (1.0)
Northeast	0.09 (0.10)	27.5 (28.1)	1.9 (2.2)
Acropora cervicornis			
Southwest	0.02 (0.06)	8.2(9.0)	0.2 (0.5)
Cayo Lobos	0.07 (0.09)	14.7 (15.0)	0.5 (1.1)
Southeast	NR	NR	NR
Northwest	NR	NR	NR
Cayo Norte	NR	NR	NR
Northeast	NR	NR	NR

Standard deviations in parenthesis

NR no colony registered

could be considered as key conservation areas for *Acropora* spp.. However, the established core areas in the management plan of Chinchorro Bank do not include these prime SE areas, because the core areas (Fig. 1) were only based on fisheries criteria (INE/SEMARNAP 2000). Although, spiny lobster and queen conch fisheries are threatened in Chinchorro Bank (Chávez and Hidalgo 1987), there are other threats such as tourism development on the southeast coast of the Yucatán Peninsula that will impact this reef in the foreseeable future (Carricart-Ganivet and Beltrán-Torres 1998; Sosa-Cordero 2003). Additional criteria, as presented in this paper, should be considered when establishing new core areas in Chinchorro Bank. Based on these results and considering that the species produces landscape heterogeneity, which in turn generates shelter for other species, including some of considerable economic importance, at least the SE region should be considered as a key area for *Acropora* species conservation, and should be included in the Chinchorro Bank management plan.

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References

Aronson RB, Precht WF (2001a) Evolutionary paleoecology of Caribbean reef corals. In: Allmon WD, Bottjer DJ (eds) Evolutionary paleoecology: the ecological context of macroevolutionary change. Columbia University Press, New York, pp 117–233

Aronson R.B, Precht WF (2001b) White-band disease and the changing face of Caribbean coral reefs. Hydrobiologia 460:25–38

Aronson RB, Macintyre IG, Precht WF, Murdoch TJT, Wapnick CM (2002) The expanding scale of species turnover events on coral reefs in Belize. Ecol Monogr 72:233–249

Bak RMP, Engel MS (1979) Distribution, abundance and survival of juvenile hermatypic corals (Scleractinia) and the importance of life history strategies in the parent coral community. Mar Biol 54:341–352

Bak RMP, Meesters HE (1998) Coral population structure: the hidden information of colony size-frequency distributions. Mar Ecol Prog Ser 162:301–306

Bass DK, Miller IR (1996) Crown of thorns, starfish and coral surveys using the manta tow and scuba search techniques. Long-term monitoring of the Great Barrier Reef. Australian Institute of Marine Science, Townsville

Bothwell AM (1981) Fragmentation, a means of asexual reproduction and dispersal in the coral genus *Acropora* (Scleractinea: Astrocoeniida: Acrporidae)—a preliminary report. Proc 4th Int Coral Reef Symp 2:137–144

Bruckner AW, Bruckner RJ (2001) Condition of restored *Acropora palmata* fragments of Mona Island, Puerto Rico, 2 years after Furtuna Reefer ship grounding. Coral Reefs 20:235–243

Bythell JC, Hillis-Starr Z, Rogers CS (2000) Local variability but landscape stability in coral reef communities following repeated hurricane impacts. Mar Ecol Prog Ser 204:93–100

Carricart-Ganivet JP, Beltrán-Torres AU (1998) Chinchorro Bank: a threatened Mexican Caribbean atoll. Coral Reefs 17:36

Carricart-Ganivet JP, Padilla-Saldívar JA, García-Gil G, Arias-González E, Acosta-González G, Membrillo-Venegas N, Castro-Pérez JM (2002) Sistema de información geográfica de Banco Chinchorro, Quintana Roo, México. Disco Compacto. El Colegio de la Frontera Sur, México

Chávez EA, Hidalgo E (1987). The human impact on the coral reef environment in Mexico. In: Proceedings of the workshop México-Australia in marine science. Mérida, Yucatán, México, pp 81–86

Chávez EA, Hidalgo E, Izaguirre MA (1985) A comparative analysis of Yucatan coral reefs. Proc 5th Int Coral Reef Congr 6:355–361

Dodge RE, Logan A, Antonius A (1982) Quantitative reef assessment studies in Bermudas: a comparison of methods and preliminary results. Bull Mar Sci 32:745–760

Federal Register (2006) Endangered and threatened species: final listing determinations for Elkhorn Coral and Staghorn Coral. vol. 71, no. 89, pp 26852–26861

Geister J (1977) The influence of the wave exposure on the ecological zonation of Caribbean coral reef. Proc 3rd Int Coral Reef Symp 1:23–29

Goreau TF (1959) The ecology of Jamaica coral reefs I. Species composition and zonation. Ecology 40:67–89

Hughes TP (1984) Population dynamics based on individual size rather than age: a general model with a reef coral example. Am Nat 123:728–795

INE/SEMARNAP (2000) Programa de Manejo Reserva de la Biosfera Banco Chinchorro. Mexican Federal Government, Mexico City

Jackson JBC (1991) Pleistocene perspectives of coral reef community structure. Am Zool 32:719–731

Jordán E, Martin M (1987) Chinchorro: morphology and composition of a Caribbean atoll. Atoll Res Bull 310:1–320

Lang J, Alcolado P, Carricart-Ganivet JP, Chippone M, Curran A, Dustan P, Gaudian G, Geraldes F, Gittings S, Smith R, Tunnell JW, Wiener J (1998) Status of coral reefs in the northern areas of the wider Caribbean. In: Wilkinson C (ed) Status of coral reefs of the world: 1998. Australian Institute of Marine Science, Townsville, pp 123–134

Loya Y (1972) Community structure and species diversity of hermatypic corals at Eliat, Red Sea. Mar Biol 13:100–123

Loya Y (1976) Effects of water turbidity and sedimentation on the community structure of Puerto Rican Corals. Bull Mar Sci 26:450–466

Norma Oficial Mexicana NOM-059-ECOL-2001 (2002) Protección ambiental-especies nativas de México de flora y fauna silvestres-categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-lista de especies en riesgo. Diario Oficial de la Federación, segunda sección (1). Marzo 6 del 2002, México, DF

Pandolfi JM (2002) Coral community dynamics at multiple scales. Coral Reefs 21:13–23

Prahl HV, Erhardt H (1985) Colombia, corales y arrecifes coralinos. Presencia, Bogotá

Rogers CS, Suchanek TH, Pecora FA (1982) Effects of hurricanes David and Frederic (1979) on shallow *Acropora palmata* reef communities: St. Croix, U. S. Virgin Islands. Bull Mar Sci 32:532–548

Sosa-Cordero E (1994) Principales pesquerías del sur de Quintana Roo: Evolución reciente, avances y perspectivas. In: Yañes-Arancibia A (ed) Recursos faunísticos del litoral de la Península de Yucatán. Universidad Autónoma de Campeche, México, EPO-MEX Serie Científica. 2, pp 57–73

Sosa-Cordero E (2003) Trends and dynamics of the spiny lobster, *Panulirus argus*, resource in Banco Chinchorro, México. Bull Mar Sci 73:203–217

Sosa-Cordero E, Medina-Quej A, Ramírez-González A, Domínguez-Viveros M, Aguilar-Dávila W (1993) Invertebrados marinos explotados en Quintana Roo. In: Salazar-Vallejo SI, González NE (eds) Biodiversidad Marina y Costera de México. Com. Nal. Biodiversidad y CIQRO, México, pp 709–734

Vargas-Ángel B, Thomas JD, Hoke SM (2003) High-latitude *Acropora cervicornis* thickets off Fort Lauderdale, Florida, USA. Coral Reefs 22:465–473

Veron JEN (2000) Corals of the world. Australian Institute of Marine Science and CRR Qld Pty Ltd, Townsville

Vogt H (1995). Video image analysis of coral reefs in Saudi Arabia: a comparison of methods. Beitr Palaeontol 20:99–105

Vollmer VS, Palumbi SR (2002) Hybridization and evolution of reef coral diversity. Science 296:2023–2025

Wallace C (1999) Staghorn corals of the world: a revision of the coral genus *Acropora*. CSIRO, Collingwood