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Natural Disturbances and Mining of Panamanian Coral Reefs by Indigenous People

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Abstract: *Before the 1980s, coral reefs were considered relatively stable and healthy in Kuna-Yala, Caribbean Panama. During the 1980s, however, several natural disturbances changed the reef's community structure. We evaluated historical changes in coral cover and for the first time provide quantitative evidence of a large-scale process of reef degradation. This process started long before the onset of these disturbances as a result of demographic growth and the traditional practices of the Kuna people. Living coral cover declined 79% in 30 years (1970–2001) while the indigenous population increased 62%. We measured 20 km of seawall built with mined reef corals (16,000 m^3) and an increase in island surface area of 6.23 ha caused by coral land filling. Consequently, coastal erosion has increased as a result of the lack of a protective natural barrier and a 2.0 cm/year local increase in sea level. Coral-mining and land-filling practices to accommodate population expansion and mismanagement of resources have significantly modified the reef ecosystem and will have serious long-term consequences. We propose eight priority conservation areas within the Indian reserve, based on reef conservation status. The Kuna people and their leaders are considering a cultural change, which may include a gradual and organized migration to the mainland, and have optimistically accepted our results.*

Perturbaciones Naturales y Explotación de Arrecifes Coralinos Panameños por Habitantes Nativos

Resumen: *Antes de 1980, se consideraba que los arrecifes coralinos eran relativamente estables y sanos en Kuna-Yala, en el Caribe panameño. Sin embargo, durante la década de 1980, varias perturbaciones naturales cambiaron la estructura de la comunidad arrecifal. Evaluamos cambios históricos en la cobertura de coral y por primera vez proporcionamos evidencia cuantitativa de un proceso de degradación de arrecifes a gran escala. Este proceso comenzó mucho antes del inicio de estas perturbaciones, debido al crecimiento demográfico y a las prácticas tradicionales de los Kuna. La cobertura de coral vivo decreció en un 79% en 30 años (1970–2001) mientras que la población indígena incrementó en un 62%. Medimos un muro de contención de 20 km construido con corales (16,000 m^3) y el incremento de 6.23 ha en la superficie de la isla por el relleno con material coralino. En consecuencia, la erosión de la costa se ha incrementado debido a la falta de una barrera natural de protección y el incremento local de 2.0 cm/año del nivel del mar. La extracción de coral y las prácticas de relleno de terrenos para acomodar la expansión poblacional y el manejo inadecuado de recursos han modificado al ecosistema arrecifal significativamente y tendrán serias consecuencias a largo plazo. Con base en el estatus de conservación del arrecife proponemos ochos áreas prioritarias de conservación dentro de la reserva Indígena. Los Kuna y sus lideres están considerando un cambio cultural, que puede incluir una migración gradual y organizada al continente, y han aceptado nuestros resultados con optimismo.*

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Introduction

For many years, anthropogenic environmental disturbances have been associated with industrialized and sophisticated societies (Goudie 2000; Lentz 2000). It is recognized, however, that centuries of resource exploitation by nonindustrialized societies have caused severe alterations to the structure and functioning of coastal marine ecosystems (Cooke 1997; Lentz 2000; Jackson et al. 2001). This view has changed our interpretation of the interactions between humans and nature, particularly in the case of modern indigenous societies.

The work of several researchers has significantly contributed to our understanding of the traditions of the Kuna people, perhaps the most successful indigenous culture of the tropical Americas. Nevertheless, their traditional practices, which have disrupted marine ecosystems, particularly coral reefs (Porter & Porter 1973), have either not been properly examined or have been accepted with indulgence (Tice 1995; Ventocilla et al. 1995; Herlihy 1997; Howe 1998).

For centuries the Kuna inhabited the tropical forests between Colombia and Panama, earning their living from mainland resources. They migrated in the mid-nineteenth century to coastal areas, populating islands near the mainland and river deltas and exploiting marine resources (Tice 1995; Ventocilla et al. 1995; Herlihy 1997; Howe 1998). In 1938 the Kuna attained political, social, and cultural autonomy in Panama (Tice 1995; Ventocilla et al. 1995; Herlihy 1997; Howe 1998). Local authorities or leaders representing each village, unified by a political authority called the Congreso General Kuna that deals with the Panamanian government, independently manage Kuna Yala (Tice 1995). Under the Panamanian constitution of 1972, new political boundaries were established in Kuna Yala, and the Comarca was divided into four *corregimientos*: Obaldia, Tubuala, Ailigandi, and Nargana. This caused a cultural change that affected the political administration of Kuna Yala. Each *corregimiento* has a Kuna representative responsible for economic development and political affairs (Tice 1995).

The coral reefs of Kuna-Yala are considered the best developed in Panama and are representative of the western Caribbean (Ogden & Ogden 1994; Porter 1974; Guzmán & Guevara 2001). Previous research has demonstrated a dramatic decline in coral cover and an increase in algal cover for reefs in the Gulf of San Blas, which has been affected by a variety of natural and human disturbances (Lasker et al. 1984; Ogden & Ogden 1994; Shulman & Robertson 1996). The impact caused by the Kuna Indians has never been quantified, even though it was reported several years ago that "a very delicate balance between a native Indian culture and its environment is in the early stages of demise" (Porter & Porter 1973).

To assess the historical and ongoing degradation of coral reefs in Kuna-Yala and its potential cultural and conservation implications, we first developed a historical record of the changes in living coral cover, demographic growth, and sea level. Second, we obtained estimates of past coral-mining activities; and third, we measured live coral cover across the entire reserve to identify potential areas for conservation, as requested by Kuna leaders.

Methods

The reserve, or Comarca Kuna-Yala (San Blas), is located along the eastern Caribbean coast of Panama, from Punta San Blas (lat. 9°34′N, long. 78°58′W) to Puerto Obaldia (lat. 8°40′N; long. 77°25′W). It encompasses 320,600 ha of continental forest and adjacent coastal waters, including approximately 480 km of coastline surrounded by reefs and mangroves and an archipelago of 365 coral islands.

In compiling historical data on live coral cover for 1971–1973 and for 1983, we relied on the works of Porter (1974) and Shulman and Robertson (1996), respectively. Data for the remaining years (1987–2001) were based on our own unpublished information. In addition, between May and June 2001 we conducted the first large-scale survey along Kuna-Yala, from Punta Anachukuna to Punta Porvenir (Obaldia was not included). The survey aimed to describe reef structure, evaluate the state of the reefs for management, and identify diversity hotspots and conservation priority areas across the Comarca. We used previously implemented standard methods (sensu Guzmán & Guevara 2001). Briefly, we assessed the species diversity (presence/absence) of hard corals (scleractinians and *Millepora*), soft corals (octocorals), and sponges during 80-minute surveys on 56 reefs. We visually estimated the percentage of cover of major sessile organisms (e.g., corals, sponges, macroalgae, coralline algae) and the density of sea urchins (*Diadema antillarum*) in 35 reefs by using a 1-m^2 quadrat subdivided into 100 grids of 100 cm^2. Three 8-m^2 transects were randomly positioned parallel to the shore at 4 depths (1–3, 10, 15, and 20 m), for a total of 3216 m^2 surveyed. The number of new coral recruits was recorded to determine reef recovery, based on individuals of $\leq$4 cm in diameter (Edmunds & Carpenter 2001).

We obtained local population growth data from government censuses (Contraloría General de la República 1998, 2001), excluding existing communities outside Kuna-Yala that had migrated to other areas of Panama (De Gerdes 1997).

Sea-level data were taken from the instrumental records of the Cristóbal hydrological station, located at the Caribbean entrance of the Panama Canal, about 80 km northwest of Kuna-Yala. The former Panama Canal Commission, in collaboration with the National Oceanographic Data Center in Hawaii, operated the station until 2000. We note that tide instruments measure "relative sea level" variations due to both land vertical movements and real changes in ocean level. Vertical movements can result from various natural causes such as tectonic processes, subduction, and earthquakes and from anthropogenic activities such as groundwater extraction and mining.

To assess the impact of coral mining and potential erosion, we used two methods. First, we measured the length, width, and height of coral walls with a metric tape on inhabited islands and estimated the volume accordingly. Second, we compared aerial photos at a scale of 1:20,000 from 1966 to 2001 to measure changes in the islands' surface areas (inhabited and farther uninhabited islands). Each island was scanned at 3000 dpi resolution with a UMAX Powerlook-3000 scanner (UMAX Technologies, Fremont, California), and the outlines of the islands were digitized with the SigmaScan-Pro 5 (SPSS Science, Chicago). Scale resolution was enhanced and calibrated with on-site measurements of permanent landmarks common to all years (e.g., piers, churches, schools).

We used a Kruskal-Wallis one-way analysis of variance on ranks, followed by Dunn's pairwise multiple comparison to test benthic cover among areas and depths and Spearman's rank to test relationships. We used regression analysis to test overall trends in coral cover, population growth, and sea level. We used SigmaStat 2.03 for the statistical analyses.

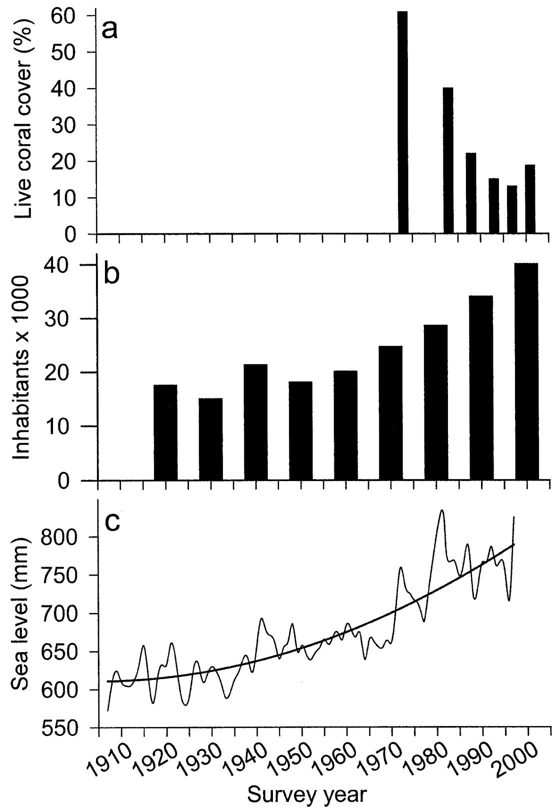

Figure 1. Changes in (a) percent living coral cover from 1971–1973 to 2001 in shallow reefs near El Porvenir, Kuna-Yala; (b) indigenous population between 1920 and 2000; and (c) sea level between 1907 and 2000. Sea level was standardized with a 3-year moving average, and the regression line represents a second-order polynomial.

Results

We assembled three long-term data sets (Fig. 1). Live hard-coral cover declined significantly ($R^2 = -0.956$, $p = 0.01$) from approximately 60% in the early 1970s to 13% by 2000 (Fig. 1a). The Kuna population increased significantly ($R^2 = 0.962$, $p = 0.001$), about 60%, from 1920 to 2000 (Fig. 1b). In addition, a gradual and significant increase in sea level was recorded for Panama ($R^2 = 0.805$, $p < 0.001$) that has averaged 2.0 cm/year since 1907 and 2.4 cm/year for the last 30 years (Fig. 1c).

The total coral-wall length was 19,645 m, with an overall mean of 935 m ± 119.7 (SE) for 21 inhabited islands (Table 1). This corresponds to a coral wall volume of approximately 16,215 m^3. We estimated a total increase of 62,289 m^2 in surface area for several populated islands (93%) as a result of coral landfilling (from 382,078 to 444,367 m^2), with an average of 4449 ± 1034 m^2 and an increase of 190% in one village (Table 2). In contrast, we found a reduction in surface area of 50,363 m^2 (from 664,954 to 614,591 m^2), with an average loss of 4578 ± 1105 m^2 (Table 2) on uninhabited islands. We measured a surface loss between 1966 and 2001 of up to 50% on one island.

We estimated 21.4% ± 2.9%, 19.6% ± 1.6%, and 29.4% ± 1.6% in live coral cover for the *corregimientos* of Tubuala, Ailigandi, and Nargana, respectively (Fig. 2a–c). The mean live coral cover was significantly higher in Nargana ($H = 19.184$, $p < 0.001$). The highest coral cover (scleractinians and *Millepora*) was half the average that existed in the 1970s (Porter & Porter 1973), with 23.8% ± 0.3 (8–37%) coral cover for the whole Comarca (Fig. 2d). Live coral cover was lower and relatively similar in shallow reefs (22.8% ± 2.1) compared with intermediate depths of 10 m (26.5% ± 1.9) and 15 m (27.4% ± 2.3) but was significantly different ($H = 8.93$, $p = 0.03$) from deep reefs (>20 m; 19.7% ± 2.9). Furthermore, live coral cover and distance from the coast were directly related ($r_s = 0.593$, $p < 0.001$), indicating higher reef deterioration near the coastline and inhabited areas.

We recorded 69 scleractinian coral, 38 octocoral, and 82 sponge species in Kuna Yala. High coral cover coincided with a higher diversity of corals ($r_s = 0.43$, $p = 0.003$), octocorals ($r_s = 0.37$, $p = 0.01$), and sponges ($r_s = 0.39$, $p = 0.007$).

Table 1. Estimate of the length and volume of coral walls measured at 21 inhabited islands in Kuna-Yala, Panama.

*Site no.**	*Island*	*Length (m)*	*Volume (m^3)*
1	Coetupu	1205.2	367.5
2	Ustupu	2529.0	835.5
3	Mamitupu	752.0	366.4
4	Achutupu	1476.0	654.4
5	Ailigandi	1310.0	971.5
6	Playon Chico	1110.3	442.7
7	Ticantiki	1041.0	462.7
8	Rio Tigre	566.2	502.2
9	Corazon de Jesus	886.3	952.5
10	Nargana	1028.8	354.3
11	Urgandi	1703.1	917.6
12	Mamardup	871.2	581.9
13	Carti Sugdup	1238.3	860.5
14	Carti Tupile	966.1	1017.6
15	Carti Yandup	700.0	4196.9
16	Ukupdupu-Wichuwala	126.0	149.9
17	Sindup-Wchuwala	315.3	537.1
18	Casa-Garrido	323.0	900.2
19	Wichuwala	600.0	438.8
20	Nalunega	400.0	235.9
21	Korbiski	498.0	469.1

**Site numbers (islands) are different from reef sites, and locations are indicated inside rectangles in Fig. 2.*

Table 2. Change in surface area of inhabited and uninhabited islands between 1966 and 2001 in Kuna-Yala, Panama.

Island	*Initial[a] (m^2)*	*Final[b] (m^2)*	*Change m^2*	*Change %*
Inhabited				
Porvenir*	45,534	52,966	7432	16.3
Wichiwuala*	6311	14,916	8605	136.4
Nalunega*	16,202	21,332	5129	31.7
Korbiski*	1769	5128	3359	189.8
Mamitupu*	5664	5227	−437[c]	−7.7
Yandup†	10,792	12,405	1613	14.9
Tupile†	16,553	20,141	3588	21.7
Sugdup†	25,623	30,891	5267	20.6
Coibita†	3252	3834	582	17.9
Mulatupu†	12,918	15,178	2259	17.5
Máquina†	3033	3225	191	6.3
Narganá‡	74,098	89,188	15,090	20.2
Corazón‡	27,376	29,990	2614	9.5
Tigre‡	77,314	80,825	3510	4.5
Ticantiquí-1‡	61,303	64,348	3045	4.9
Uninhabited				
Limones‡	18,423	16,973	−1450	−7.9
Mosquito*	31,363	24,813	−6550	−20.9
Hotel Viejo*	19,720	9181	−10,539	−53.4
Sugar 1‡	158,193	152,152	−6041	−3.8
Sugar 2‡	34,683	30,621	−4062	−11.7
Coco-oeste 1‡	106,868	103,388	−3480	−3.3
Coco-oeste 2‡	54,534	53,477	−1057	−1.9
Coco-este‡	95,158	84,774	−10,384	−10.9
Farewell‡	92,276	86,396	−5880	−6.4
Ticantiquí-2‡	48,072	47,589	−483	−1.0

[a]*Initial measurements were based on aerial photos taken in 1966 (*), 1985 (†), and 1991 (‡).*
[b]*Recent or final measurements were based on photos from 2001.*
[c]*This negative value was added to the analysis of uninhabited islands.*

We obtained an overall mean of 0.87 ± 0.1 new juvenile corals/m^2 (0–5.1 recruits/m^2; $n = 3216$ m^2). Higher coral recruitment was observed in shallow waters (1.13 ± 0.2 recruits/m^2) but was not significantly different from that of deeper reef zones ($H = 3.355$, $p = 0.340$). Likewise, the number of recruits was similar among the *corregimientos* ($H = 2.538$, $p = 0.281$).

Macroalgae cover was 63% ± 2.3 (41–78%; Fig. 2d), and no significant differences were observed among the three *corregimientos* ($H = 4.958$, $p = 0.084$) or between depths ($H = 5.398$, $p = 0.145$). The mean population density of grazer *Diadema antillarum* in Kuna-Yala was 0.1 individuals/m^2 ($n = 1656$ m^2; 1–10 m depth range).

Discussion

Reef degradation in Kuna Yala is complex to evaluate because it results from a combination of relatively recent natural disturbances (<15 years) and several decades of continuous anthropogenic disturbances. Since the 1980s, natural disturbances have further complicated the ongoing human-made degradation of reefs, with the massive mortality of the herbivorous sea urchin *Diadema antillarum* (Lessios 1998), followed by anomalous warming in 1983 (Lasker et al. 1984) and 1995 and coral diseases that affected all Caribbean reefs, particularly the *Acropora* coral species (Gladfelter 1982; Shulman & Robertson 1996). We saw high macroalgae cover (>70%), intermediate-to-low live coral cover (23%), and population densities of *Diadema* of 0.1 per m^2 that perhaps are comparable to those within the Jamaican algal zones (Edmunds & Carpenter 2001). In addition, the prospect for recovery seems poor at present: 0.87 recruits/m^2, which is lower than that of 24 recruits/m^2 (10–43; $n = 50$ m^2) and 5.4 recruits/m^2 (1–12) recently recorded in sea urchin and algal zones from Jamaica, respectively (Edmunds & Carpenter 2001). We observed recruitment patterns that suggest a switch in composition toward typically weedy and abundant species, *Porites astreoides*, *Agaricia* spp. and *Diploria strigosa*, rather than former reef-building acroporid species (sensu Hughes & Tanner 2000; Edmunds & Carpenter 2001).

On the other hand, in response to population growth, the Kuna people have practiced coral mining and landfilling for decades. Their population has almost doubled since 1920, causing a continuous impact on shallow reef habitats over large areas. Traditionally, the Kuna have gradually enlarged their island landmass by building coral walls out into the water, usually over mined shallow-reef areas or sandy beaches, and then filled the enclosed area mainly with corals, seagrass, and sand. The walls (and landfilling) are constructed primarily of the once-abundant *Acropora palmate*, along with other massive

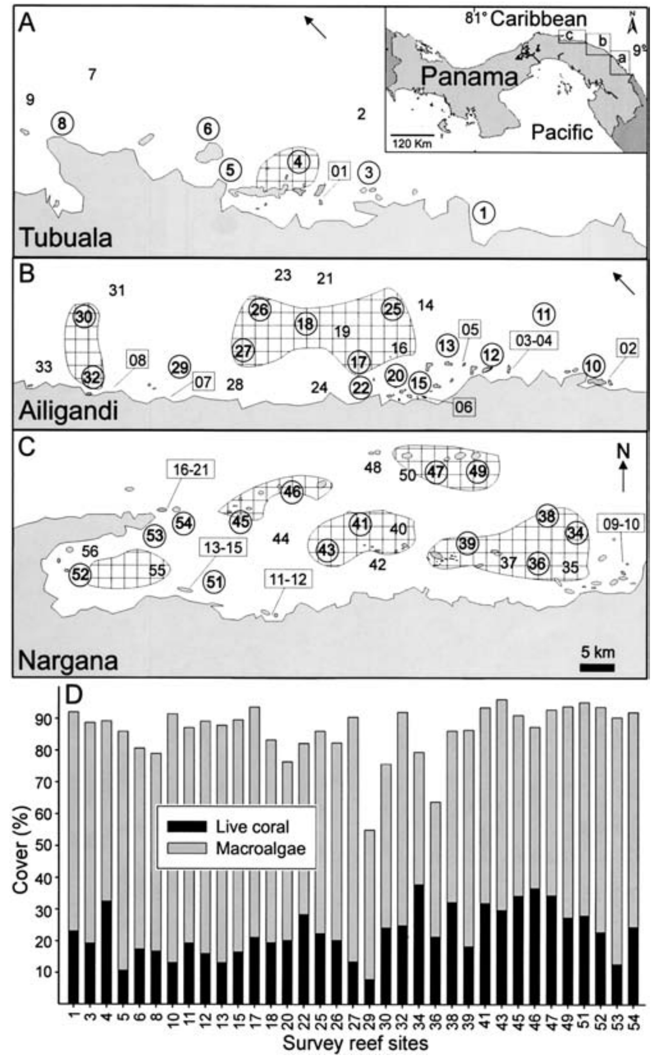

Figure 2. Study region in Panama showing the sites within each corregimiento in Kuna-Yala: (a) Tubuala (lat. 08°41′09′′N, long. 077°30′07′′W); (b) Ailigandi (lat. 09°06′44′′N, long. 077°55′11′′W); (c) Nargana (lat. 09°21′01′′N, long. 078°22′56′′W). (d) Average cover of live corals and macroalgae for reefs where structure was described in May–June 2001. Open circles indicate 35 reef sites where coral cover and species diversity (presence-absence) were studied, and numbers without circles indicate sites where only diversity was studied. Rectangles indicate the location of villages where coral wall size and volume were estimated (Table 1). Hatched polygons indicate proposed conservation priority reef areas.

coral species such as *Siderastrea* and *Diploria*. A shortage of these species has lately increased the use of the easily removable branched-finger *Porites furcata*, found abundantly in shallow reefs (0.5--2 m depth). This activity has affected both the seaward and landward sides of the islands, with the exception of the outer high-energy barrier reef, where there is little evidence of accumulation of reef framework over the last 2000 years (Macintyre et al. 2001).

We measured coral volume on visible walls (16,215 m^3), which may be used to infer habitat loss due to landfilling. Hence, we obtained an additional volume of 14,441 m^3, assuming that 70% (43,602 m^2) of the total increased area (62,289 m^2) was filled with corals up, to a minimum height of 0.4 m. This is an underestimation because we measured landfill on only 38% (14) of the existing 37 populated islands (there are 47 villages in Kuna Yala, 10 along the mainland). Instead, a conservative estimate based on our average increase (4449 m^2) extrapolated to all islands can yield up to 46,087 m^3 for landfilling, excluding coral walls.

Reef habitat loss (down to 3 m deep) around the populated islands has forced the Kuna people to mine uninhabited offshore islands. We measured a net loss in surface area, which may be attributed to erosion during storms and unusually high tides. Erosion rates may have been enhanced by the gradual increase in the eustatic sea level recorded for Panama (similar to Cartagena, Colombia) and by tectonic subsidence in this area (Coates & Obando 1996). Erosion processes have affected the Kuna for decades (Porter & Porter 1973), but more so recently, forcing them to build coral breakwaters as high as 2 m on populated islands in response to the loss of an effective natural protective reef barrier. *Acropora palmata* is considered one of the main reef-building species in the Caribbean (Gladfelter 1982; Pandolfi & Jackson 2001). It plays an essential role in the protection of coastal areas, and, even more important, during periods of sea-level rise the species is able to keep pace and accrete vertically (Pandolfi & Jackson 2001; Kennedy & Woodroffe 2002).

The functions of the reef structure and the ecosystem may have changed in response to loss of reef habitat loss to mining and to the concomitant increase in macroalgae cover that outcompetes coral growth and recruitment of new corals (Ogden & Ogden 1994; Lessios 1998; Edmunds & Carpenter 2001). Both disturbances have contributed at different levels to the gradual demise of reefs, and we expect long-lasting effects to initiate recovery (sensu Pearson 1981).

Despite the aforementioned disturbances, Kuna-Yala contains the country's highest coral diversity (Guzmán & Guevara 2001), which has increased from 49 (Porter 1972) to 69 with this study. Optimistically, and at the request of Kuna leaders, a major goal of this study was to identify potential conservation areas within the Comarca. We propose a network of eight manageable conservation units in Kuna-Yala (Fig. 2a–c), five of which should be located within the largest populated region of Nargana (Fig. 2c). The areas were chosen based on a combination of any of the following criteria: cultural organization (Tice 1995; Howe 1998), distance from populated centers, highest species diversity, overall live-coral cover, and populations with a low-to-moderate cover of now endangered or rare corals *Acropora palmata* and *A. cervicornis* (Precht et al. 2002). We weighted cultural organization (e.g., property ownership, organized authorities in nearby villages) as one of the most important factors, and we believe that the Kuna people ought to decide the management scheme.

The future protection of Kuna-Yala marine ecosystems depends on Kuna and non-Kuna people working together to solve conflicts associated with the traditional use of reefs and to preserve the cultural autonomy of the Kuna and the sustainability of their resources. The extensive archipelago may continue to support Kuna inhabitants and render an indirect service to the conservation of other remote reef areas across the Western Caribbean if biological connectivity (Roberts 1997; Hughes & Tanner 2000) and diversity (Guzmán & Guevara 2001; this study) can be maintained.

Connectivity and diversity can be preserved if coral mining and other natural disturbances do not further depress reef growth and recovery. Finally, the struggle for survival of this successful Neotropical indigenous culture may rely on a change in attitude toward the conservation of marine habitats (Porter & Porter 1973; De Gerdes 1997), a process that has already been initiated.

Acknowledgments

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