A window to the past: documenting the status of one of the last remaining ‘megapopulations’ of the threatened staghorn coral Acropora cervicornis in the Dominican Republic

D. LIRMANa, A. BOWDEN-KERBYb, S. SCHOPMEYERa, B. HUNTINGTONa, T. THYBERGa, M. GOUGHc, T. GOUGHc, R. GOUGHc and Y. GOUGHc

a University of Miami, Rosenstiel School of Marine and Atmospheric Science, 4600 Rickenbacker Cswy, Miami, FL 33149, USA
b Corals for Conservation, Suva, Fiji
c Reef Check, Dominican Republic

ABSTRACT

1. Acropora cervicornis (staghorn coral) and Acropora palmata (elkhorn coral), once common features of shallow Caribbean reefs observed growing as large stands or thickets, are now found mainly as remnant pockets or isolated colonies at a fraction of their historical areal extent.

2. In February 2010, a large, surviving population of A. cervicornis was surveyed at Cabezos del Cayo, Punta Rusia, Dominican Republic to document its present condition and potential threats to its persistence.

3. The A. cervicornis surveyed at Cabezos del Cayo provides a rare glimpse of the habitat structure that these keystone components of coral reefs once provided. The staghorn population covers an area of 2 ha and is formed by interlocking skeletons of unusually large and thick A. cervicornis colonies.

4. The large size of its colonies (maximum branch length 250 cm; average linear length of live tissue 471 cm; maximum number of branch tips 141 per colony; maximum branch diameter 5 cm) and the complex open canopy of these colonies, have not been described, to our knowledge, in the recent literature.

5. The site is within Montecristi National Park but there is no active protection in this area and signs of overfishing are evident based on low fish abundance and complete lack of fish >20 cm in length.

6. The stressors associated with this population include significant predation by gastropods and fireworms, overgrowth by macroalgae, damselfish ‘gardening’ activities, and white band disease.

7. The management priority for the staghorn population at Cabezos del Cayo, Dominican Republic, should be to enforce the legal framework that is already in place for the protection of Montecristi National Park, limiting unsustainable and damaging fishing practices, and limiting land-based sources of pollution associated with increasing population numbers and future coastal development.

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INTRODUCTION

The protection and recovery of coral species that have experienced drastic declines has become a focus of attention for coral reef managers and scientists. This is especially true for the Caribbean genus Acropora, which has undergone significant regional declines in abundance and condition that have prompted its listing as ‘threatened’ under the US Endangered Species Act (Aronson and Precht, 2001a; Precht et al., 2002; NMFS, 2006). The factors associated with the decline of Acropora in the Caribbean are those identified for other species and regions, and include epizootic outbreaks (Gladfelter, 1982; Aronson and Precht, 2001b), hurricanes (Woodley et al., 1981; Lirman and Fong, 1997), extreme temperature events (Jaap and Sargent, 1994), predation (Knowlton et al., 1990; Miller et al., 2002), and other stressors (Bruckner, 2002). The consequence of the loss of
live tissue cover from staghorn (*Acropora cervicornis*) and elkhorn (*Acropora palmata*) colonies caused by these disturbances can extend well beyond immediate impacts. As members of one of the key reef-building genera in the region (Adey, 1978; Lighty et al., 1982), reductions in live coral cover results ultimately in a loss of reef structure and associated ecological, economic, and societal services provided by this three-dimensional structure (Alvarez-Filip et al., 2009; Paddack et al., 2009). The tools proposed for the recovery of this genus at the local and regional levels include the establishment of marine protected areas (MPAs), controls on land-based sources of pollution, and active propagation and restoration (Bruckner and Hourigan, 2002; Miller and Szmant, 2006; Herlan and Lirman, 2009; Lirman et al., 2010).

While large living stands or thickets of *Acropora* colonies were once common features of shallow Caribbean reefs (Goreau, 1959; Drost and Halas, 1987; Aronson and Precht, 1997), remnant staghorn and elkhorn populations now appear mainly as small pockets or isolated colonies at a fraction of their historical areal coverage (Davis, 1982; Miller et al., 2002, 2009). The reduction in the size of remnant living populations and the increased spatial isolation caused by the severe decline pose additional threats to the recovery of this genus by limiting sexual reproduction potential (Baums et al., 2006) Thus, the discoveries of large, living populations that can be important sources of both genotypic diversity and sexually produced propagules, are infrequent but clearly positive findings for the future recovery of this genus (Vargas-Angel et al., 2003; Keck et al., 2005).

In 2004/2005, divers and scientists reported the sighting of a large, living population of *A. cervicornis* on the north coast of the Dominican Republic, within Montecristi National Park. Since then, this population has been visually assessed at irregular intervals but no quantitative data on its structure and status were collected. In this study, we describe the present condition of this population to establish a baseline for future change detection and to evaluate potential threats to its persistence. The site at Cabezos del Cayo, Punta Rusia, Dominican Republic, was surveyed in February 2010 using a variety of field methods aimed at documenting: (1) spatial extent of the staghorn population; (2) percentage cover of live coral tissue and macroalgae; (3) amount of live tissue, number of branches, branch diameter, height, and percentage partial mortality of staghorn colonies; (4) abundance of territorial damselfish and coral predators (i.e. gastropods, fire worms); (5) prevalence of diseases, bleaching, and coral predation; (6) abundance and species richness of reef fish; and (7) coral species richness. Key attributes of this population (e.g. colony size, tissue mortality patterns, associated fish communities) are compared with a regional database that includes more than 800 sites surveyed in the Caribbean to evaluate the comparative status of this unique and increasingly rare resource.

**METHODS**

Surveying large, complex populations of branching corals with interlocking skeletons poses a logistical challenge. Thicket morphology, in which one colony boundary can become indistinguishable from another often limits the surveyor’s ability to assess colony-based demographic traits for *Acropora* populations. Here, we used the point-intercept method applied to digital images of the bottom to measure percentage cover of corals and other organisms (Kohler and Gill, 2006). In addition, individual staghorn colonies were surveyed to provide information on colony size, tissue mortality patterns, and stressor prevalence. The demographic (i.e. colony-based) approaches to the assessment of *Acropora* stands implemented here are adapted from previous work by Vargas-Angel et al. (2003), Grober-Dunsmore et al. (2006) and Williams et al. (2006). These methods, complemented by fish and coral predator surveys, provide a comprehensive assessment of the status of staghorn populations and collects information on diverse baseline metrics against which future changes can be fully ascertained. The unusual morphology of the staghorn colonies (i.e. large colonies, open canopy) provided a better opportunity to track individual skeletal units and allowed for good characterization of colony-based metrics, which could have been extremely challenging in thickets with smaller colonies and very tight canopies, as shown by Vargas-Angel et al. (2003) in Florida and Keck et al. (2005) in Honduras.

The outline of the main *A. cervicornis* population was delineated, from the surface, by a snorkeler holding a GPS unit while recording a continuous track. The staghorn population has a distinct edge as dense staghorn colonies transition into sand, seagrass, or mixed communities dominated by other species, allowing for a clear determination of the patch boundaries. While isolated colonies of *A. cervicornis* were observed beyond the patch boundaries, the dense thicket aggregations were all included within the delineated boundaries. The track was used to determine the spatial extent of the population.

Sampling within the staghorn patch was conducted using 18 haphazardly deployed 10 m linear transects (depth = 4–8.5 m). All the *A. cervicornis* colonies with live tissue intersected by each line transect were surveyed to obtain the following metrics: (1) the total linear length of live tissue; (2) the percentage of the whole colony that had live tissue; (3) number of branch tips and branch tips showing signs of recent mortality; (4) maximum branch diameter (living branches only); (5) colony height estimated as the length of longest (or tallest) branch; and (6) percentage recent partial mortality. Data were averaged within transects. Individual staghorn colonies are often hard to distinguish within interlocking frameworks. However, the large size of colonies and the open canopy of the staghorn patch at Cabezos del Cayo allowed divers to distinguish (to the best of their abilities) individual colonies in this study. Individual colonies were defined as those ramets possessing a single basal attachment to the bottom. Colonies adjacent to each other that exhibited fused branches were considered as a single colony in these surveys. The total linear length of live tissue on each colony was estimated by adding up the lengths of all live branches and tissue isolates. Recent partial mortality was considered as any portion of the skeleton devoid of living tissue but still retaining calyx and skeletal structure devoid of significant algal overgrowth. This metric is included to provide an indication of tissue mortality that took place within a few months of the time of survey (Kramer and Lang, 2003). In addition to the coral metrics, the presence of urchins, corallivorous gastropods, damselfish lawns, and evidence of recent predation by the polychaete worm *Hermodice carunculata* were noted. The presence of white tips was used as a proxy for fireworm predation since these organisms, often active at night (Marsden, 1962), were...
not directly observed during these day-time surveys. Lastly, the colonization of macroalgal taxa on the coral skeleton was noted for each colony.

A survey of corallivorous snails was conducted within the coral transects. In addition, roving-diver surveys (four 1 h surveys) were conducted and all snails observed were collected by hand, identified, and measured.

Digital images were collected along each transect at a distance of roughly 50 cm from the top of the coral colonies to document percentage cover of corals and macroalgae using the point-intercept method. Twelve non-overlapping images were selected along each transect and 25 random points were superimposed onto each frame as described by K水质l and Gill (2006). Each image captured roughly 0.25 m$^2$ of the bottom for a total area surveyed within each transect of approximately 3 m$^2$. The minimum number of images and points needing to be analysed were determined based on preliminary analyses conducted using methods described in detail by Brown et al. (2004). The benthic taxon or category immediately under each point was identified (e.g. live and dead coral, macroalgae, other organisms) and the proportional abundance (cover) was assessed for each category. Data were averaged within transects.

Twelve fish transects were surveyed (depth 4–10 m) using the Atlantic and Gulf Rapid Reef Assessment (AGRRA) methodology (Kramer and Lang, 2003). Each transect (30 m × 2 m) was visually surveyed to document abundance and sizes of all reef fish observed. Fish lengths were assigned to one of six size categories (0–5, 6–10, 11–20, 21–30, 31–40, >40 cm). Finally, a cumulative species richness count for stony corals and reef fish was performed by roving divers during five 60–90 min dives.

**RESULTS**

The staghorn population at Cabezos del Cayo is located on the north coast of the Dominican Republic in the Punta Rusia area (19° 52.556’ N, 71° 19.847’ W; Figure 1). Its longest axis is 300 m and its widest axis is 100 m. The surface area of the population is approximately 20000 m$^2$ or 2 ha. The staghorn population appears as a semi-continuous patch of interlocking *A. cervicornis* skeletons with a limited number of other stony coral species found within the staghorn framework. The population extends from the leeward side of the shallow back-reef area of a non-emergent reef (2 m) towards shore where it reaches depths of 10–12 m. At present, live coral colonies are found at highest densities as isolated foci within the larger patch. These pockets of high live coral cover can be up to 30 m in diameter (Figure 2). In addition to these high-cover areas, live staghorn colonies (at lower densities) are scattered throughout the patch. Several areas, especially in the deepest portions of the patch, are almost completely devoid of live tissue but still exhibit the high structural complexity of live patches, suggesting a recent demise of the corals found there and limited short-term bioerosion and breakage. The distance between the tallest coral colonies and the substrate often exceeds 2 m (Figure 2).

The mean linear length of live tissue (i.e. the sum of all live branches and tissue isolates on each colony) on staghorn colonies was 335.1 cm (S.D. = ± 285.8, $n = 133$ colonies). Most of the colonies surveyed were large, and mean colony height was 85.6 cm (41.7), with a maximum branch length of 250 cm. The staghorn population structure is positively skewed (i.e. fewer very large colonies), but still >25% of colonies had branches exceeding 1 m in length (Figure 3). The mean number of colonies intersected by each 10 m linear transect was 7.4 (3.6), with a minimum of two colonies and a maximum of 18 colonies per transect. The mean diameter of branches exceeded 2 cm and the largest colonies had a maximum branch diameter of 5 cm. Colony size (total linear tissue length) was significantly related to maximum branch diameter (linear regression, $r = 0.7$, $P < 0.001$, $n = 133$). The colonies also had very complex branching patterns, with a mean > 20 branch tips per colony and a maximum of 141 branch tips per colony. On average, staghorn colonies had 48.6% (14.8) of their skeleton covered by live tissue. The mean percentage recent tissue mortality was 5.1% (3.4), with a maximum of 45%.
mortality was observed at the branch tips, bases, and the middle of the branches (Figure 4). No significant relationship was found between the size of the colonies (total linear tissue length and height) and percentage recent mortality (linear regressions, $r < 0.1$, $P > 0.1$, $n = 133$).

The abundance of damselfishes (mainly three-spot damselfish, *Stegastes planifrons*, and dusky damselfish, *S. fuscus*) was high, with 30% of colonies found within damselfish territories. Predatory gastropods (*Coralliophila abbreviata*) were found on 11.3% of colonies, and evidence of fireworm (*Hermodice carunculata*) predation (i.e., tips with recent tissue mortality) was observed on 20.3% of colonies (Figure 4). The mean abundance of the predatory snail *C. abbreviata* was $2.0$ (S.D. $= 3.7$) snails per transect, with a maximum of 11 snails per transect. During roving diver surveys ($n = 4$ surveys, approximately 1 h each), a total of 143 *C. abbreviata* were collected. The mean size of the snails was 2.2 (0.7) cm. Evidence of white band disease was observed on 5.3% of staghorn colonies. The lower portions or ‘under-canopy’ of the staghorn colonies are commonly colonized by macroalgae (Figure 4). *Dictyota* was observed growing on 48% of the colonies, crustose coralline algae on 45%, and *Lobophora* on 43% of colonies. Turf (i.e., filamentous algae with canopy height <2 cm) was observed growing on 53% of colonies. No individuals of the sea urchin *Diadema antillarum* were observed within the staghorn framework although this grazer was abundant (>2–3 m$^2$) in nearby shallow back-reef environments. A total of 28 species of stony corals were observed at Cabezos del Cayo (Table 1).

The mean percentage cover of stony corals within the staghorn patch was 17.8% (S.D. $= 9.7$), the mean cover of macroalgae was 81.5% (9.7). The mean cover of live *A. cervicornis* was 10.3% (10.4) (Figure 5). On average, staghorn corals comprised 50% (27.6) of the total coral cover within the patch (range 10–90% of the total live coral cover) (Figure 5). The dominant types of macroalgae were crustose coralline algae (mean cover 22.6% (8.5)), found commonly on the top or canopy portions of the staghorn skeletons, and
Lobophora-Dictyota (58.9% (11.8)) that dominated the under-canopy or bottom portions of the dead staghorn colonies and framework (Figure 4).

Forty-four species of reef fish were observed at the Cabezos del Cayo staghorn population (Table 1). The reef fish community was dominated numerically by parrotfish (34% of all individuals), damselfish (28%), wrasse (25%), and surgeonfish (7%). No other taxa reached >1% of the total number of individuals observed in twelve 30 m × 2 m transects surveyed. The two most abundant species were Scarus croicensis (striped parrotfish; 23.6 individuals per 100 m²) and the territorial damselfish Stegastes planifrons (three-spot damselfish; 37.2 individuals per 100 m²). The abundance of economically important species like groupers (three individuals observed), snappers (five individuals), and grunts (two individuals) was extremely low (Figure 6). Moreover, the average size of those individuals observed was small, with just one fish (out of 1029), a trumpetfish (Aulostomus maculatus), >20 cm in length.

To provide a regional comparison, the data collected at Cabezos del Cayo in February 2010 were compared with similar data found in the AGRRA regional database, which contains information on coral reef status from 781 sites surveyed from 1997–2004 throughout the Caribbean (Marks, 2007). The total number of staghorn colonies within the database is 1008 (only 1.5% of stony colonies encountered) and A. cervicornis was found at 238 sites of the 781 sites surveyed (30% of sites). The mean height of the staghorn colonies within the AGRRA database is 30.0 cm (S.D. = ±16.7), considerably smaller than the average colony height at Cabezos del Cayo (85.6 cm). The mean percentage recent mortality of A. cervicornis from the AGRRA database is 5.1% (S.D. = ±14.0), which is exactly the same value recorded for the staghorn colonies at Cabezos del Cayo. The prevalence of disease for A. cervicornis is 12.9% of colonies, with 11.5% of colonies exhibiting signs of white band disease (WBD) in the region compared with only 5.3% of colonies with WBD at Cabezos del Cayo. When the reef fish community at Cabezos del Cayo was compared with the regional patterns obtained from the AGRRA database (fish data were collected at 656 sites from 1997–2004), the only taxon that showed a higher abundance, compared with the regional mean, was parrotfish. All other taxa at Cabezos del Cayo had abundances lower than the regional mean (Figure 7). The parrotfish found at Cabezos del Cayo were more abundant but also smaller than the regional mean. No parrotfish >20 cm were found in the current surveys (Figure 8).

DISCUSSION

The A. cervicornis population surveyed at Cabezos del Cayo, Punta Rusia, Dominican Republic in February 2010 provides a rare glimpse of the habitat structure that these keystone
components of coral reefs once provided before their well-documented regional decline. The size of this particular population (2 ha) pales in comparison with the staghorn population described by Keck et al. (2005) in Honduras that covers 21 ha, but the uncommon morphology of its colonies makes the Cabezos del Cayo thicket a unique resource. The presence of large colonies is three times larger than the regional mean reported for this species based on surveys of more than 800 sites throughout the Caribbean (Marks, 2007). The presence of large colonies is both an indicator of favourable growth conditions over past decades as well as a high recovery potential through sexual reproduction due to the greater reproductive output of extremely large colonies (Hall and Hughes, 1996).

The stressors associated with the staghorn population at Cabezos del Cayo include predation by gastropods and polychaete worms, overgrowth by the macroalgae Lobophora, damselfish ‘gardening’ activities, and white band disease (Carvalho et al., 2008). The stressors associated with the staghorn population at Cabezos del Cayo (values for all 12 transects surveys are added together).
disease. These disturbance factors are the same as documented for staghorn and elkhorn stands throughout the Caribbean region (Bruckner, 2002; ABRT, 2005). Prevalence of predation values at Cabezos del Cayo were similar to those recorded for staghorn populations in Florida where *Hermrodice* scars were observed in up to 29% of quadrats (Vargas-Angel et al., 2003) and *Coralliophila* snails were observed on 18% of colonies (Williams and Miller, 2006); and Jamaica, where a median of up to 10.5% of colonies hosted *Coralliophila* (Knowlton et al., 1990). Predation is also a main source of tissue mortality for elkhorn coral, with corallivorous snails observed on 6.1% of colonies in the USVI (Grober-Dunsmore et al., 2006), 18% of colonies in Puerto Rico (Bruckner et al., 1997), and up to 20% of colonies in the Florida Keys (Baums et al., 2003). Damselfishes, territorial fish that can kill coral tissue to grow their preferred macroalgal species for feeding and nesting purposes (Kaufman, 1977), were also identified as a key mortality factor for declining staghorn stands in Jamaica where up to a median of 25% of colonies exhibited the negative signs of damselfish activities (e.g. bites, algal lawns) (Knowlton et al., 1990). White band disease, an epizootic disease, is increased, it is unlikely that the depauperate grazing guild can control macroalgal overgrowth and further declines in the extent and condition of staghorn populations can be expected, as shown in other areas where the combination of overfishing and increased nutrient inputs have resulted in significant coral declines (Hughes, 1994).

The establishment of marine protected areas (MPAs) has been one of the most successful management tools available for the preservation of coral reefs and other marine habitats around the world (Halpern, 2003; Lubchenco et al., 2003). One of the key factors identified for the survivorship and recovery of coral populations within and around protected areas is the maintenance of an intact food web that includes both herbivores and carnivores that may control the populations of coral competitors such as macroalgae and coral predators such as *Coralliophila abbreviata* and *Hermrodice carunculata* (Hughes et al., 2007; Mumby et al., 2007). Even if the actual beneficial mechanisms are not well understood, marine zoning has resulted in a decrease in the frequency of outbreaks of the predatory starfish *Acanthaster plancii*, a major cause of coral mortality in the Great Barrier Reef (McCook et al., 2010). The staghorn population at Cabezos del Cayo is located within the Montecristi National Park, created in 1983 and expanded and ratified in 2000 (Garza-Pérez and Ginsburg, 2008). However, no active management and protection of the marine resources are present in this area (Linton et al., 2002), and signs of overfishing are evident from the low fish abundance and complete lack of fish >20 cm in length. The low abundance and small size of fish are similar to those found by Garza-Pérez and Ginsburg (2008) in surveys conducted in Montecristi in

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Figure 8. Size–frequency distribution of parrotfishes in the AGRRA database (grey bars) and the Cabezos del Cayo staghorn population (black bars). Juvenile parrotfishes (<6 cm) are not recorded in the AGRRA database.
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