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Ecological Status of Essential Fish Habitats Through an Anthropogenic Environmental Stress Gradient in Puerto Rican Coral Reefs.

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ABSTRACT

The status of declining marine fisheries through the wider Caribbean region has been thoroughly documented. However, there is a lack of quantitative data to determine if there is any cause and effect relationship between declining fish populations and declining ecological conditions of essential fish habitats. We have quantitatively documented the ecological conditions of essential fish habitats and fish communities through an anthropogenic environmental stress gradient in seven northeastern Puerto Rican coral reef communities. Study sites differ in fishing pressure and in water quality, factors which create an anthropogenic environmental stress gradient as we move off degraded coasts. Line intercept transects were used to assess coral reef epibenthic communities. Stationary visual censuses were used to assess fish communities. There were significant differences in the structure of coral reef epibenthic and fish communities as we moved offshore, which suggests that anthropogenic environmental stress and fishing pressure gradients can change the structure of coral reef epibenthic and fish communities. Degradation is stronger at inshore habitats, which showed lower coral species richness, percentage of living coral cover and species diversity. These habitats are also characterized by having higher algal cover, and low abundance and diversity of reef fishes. Offshore, less degraded habitats are characterized by higher coral species richness, percentage of living coral cover and species diversity. These habitats are also characterized by having lower algal cover, and high abundance and diversity of reef fishes. There were also severe overfishing effects at some of the less disturbed offshore sites, which masked the expected results for a healthy reef. Reef fish abundance and biomass was significantly lower at overfished sites. Given the alarming conditions of depleted fish stocks, even within the boundaries of Natural Reserves, we recommend the establishment of a network of small Marine Fishery Reserves (=no take zones) at Cayo Diablo, Palominitos Island, Cayo Icacos and at the western coast of Culebra Island to help restore depleted fish stocks. There is a relationship between the ecological conditions of essential fish habitats and reef fish communities. The status of essential fish habitats could affect the status of fish communities. But under the absence of significant environmental degradation, the status of fish communities could also affect the status of essential fish habitats (i.e., coral reefs). These aspects should be taken in consideration in the design of coral reef fishery management measures, including the establishment of marine fishery reserves.

KEY WORDS: Anthropogenic impacts, coral reefs, essential fish habitats.

INTRODUCTION

Within the last twenty years there has been an increasing number of reports about coral reef degradation (Hughes, 1994), coral bleaching (Williams and Bunkley-Williams, 1990), massive die-offs of coral reef fauna (Garzón-Ferreira and Zea, 1992; Nagelkerken et al., 1996), coral population declines (Garzón-Ferreira and Kielman, 1993), and reef fish population declines (Appeldoorn et al., 1992; Bohnsack, 1992; Butler et al., 1993; Roberts, 1995) throughout the Caribbean. The situation of Puerto Rican coral reefs may, in fact, be one of the most critical in the Caribbean (Goenaga and Boulon, 1992; Hernández-Delgado, 1992), possibly as a result of rapid urban and industrial development, and increasing coastal water quality degradation during the last four decades.

Declining reef fish populations have been deemed to significantly contribute to the degradation of reef communities (Bohnsack 1982, 1993). According to Roberts (1995), overfishing could lead to major shifts in reef community structure, could reduce species diversity on reefs, and could affect important reef processes as a result of the loss of keystone species, and/or the loss of functional groups of species. In addition, overfishing may cause a reduction in fish biomass, species richness, average size of target species, and the complete elimination of many large predatory species, as well as an increased skewness towards females in sex ratios of sequentially hermaphrodite parrotfishes (Roberts, 1996). Overfishing of large sized herbivores such as parrotfishes (Scaridae), following the mass mortality of *Diadema antillarum*, was also pointed out as the direct cause of the great increase in algal cover and consequent decline in living coral cover on Jamaican coral reefs (Hughes, 1994). The latter suggests that there might be a direct relationship between the ecological status of coral reef fish and epibenthic communities, and that overfishing of keystone species (i.e., large sized herbivores) might have unsuspected adverse and possibly irreversible effects on coral reefs on a human time scale.

However, it still remains difficult to differentiate between the effects of changing environmental conditions and the effects of declining fish populations in coral reef epibenthic communities. By studying the conditions of coral reef epibenthic and fish communities through an environmental stress and a fishing pressure gradient we might be able to determine if there is any relationship between these factors. This may also help us to understand the ecological conditions of part of the essential fish habitats under different environmental and fishing pressure scenarios. Our objective was to use the northeastern coast of Puerto Rico as model to characterize the structure of coral reefs epibenthic and fish communities through an anthropogenic environmental stress and fishing pressure gradient.

METHODS

STUDY SITES

Studies were carried out in coral reefs located in northeastern Puerto Rico (Figure 1). Sites were selected according to their location in relation to habitat degradation and include, from the most degraded to the less degraded site: Punta Picua, Espíritu Santo River Natural Reserve (PP), Luquillo Beach (LB), Cabezas de San Juan Natural Reserve (CSJ), Ramos Island (IR), Palominitos Island (PAL), Cayo Icacos (CI), Cayo Diablo (CD) and Carlos Rosario Beach, Culebra (CR). Sampling sites PAL, CI and CD are located within La Cordillera Natural Reserve, off Fajardo. We defined a highly degraded reef as one characterized by having a low underwater transparency, high water turbidity, high concentration of solid suspended material, high sedimentation rates, high bioerosion rates and low recruitment rates. Degraded reefs are also those which are characterized by the dominance of opportunistic and non-reef building taxa.

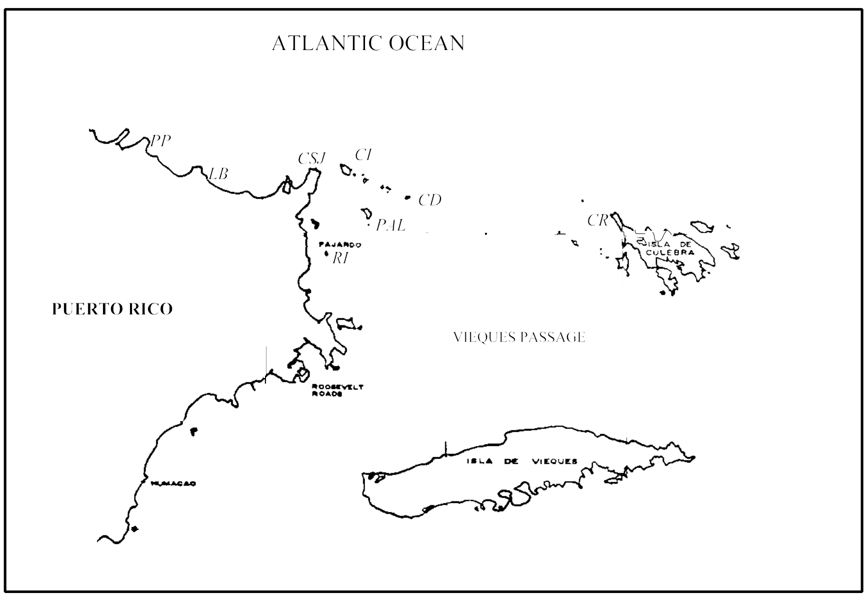

FIGURE 1. Study sites in eastern Puerto Rico. Sites are arranged from highly degraded and close to shore coral reefs (i.e., PP), to less degraded, offshore reefs (i.e., CR). PP=Punta Picua, LB=Luquillo Beach, CSJ=Cabezas de San Juan, IR=Ramos Island, PAL=Palominitos Island, CI=Cayo Icacos, CD=Cayo Diablo, CR=Carlos Rosario Beach, Culebra.

Quantitative studies of epibenthic communities were carried out in PP, LB, CSJ, IR, CI, CD and CR by using the line-intercept transect method (Loya and Slobodkin, 1971). Each permanently-marked transect was 10-m long (n=8-20/site). We determined the percentage of cover of all major epibenthic components (i.e., corals, algae), coral species diversity index, H'n (Shannon and Weaver, 1948) and evenness (Pielou, 1966a,b). Reef fish communities were described by means of the stationary visual census method of Bohnsack and Bannerot (1986). Each sampling station covered an imaginary cylinder with a radius of 7.5 m, a surface area of 176.7 m^2. Data was obtained within a period of 15 min per station. Fish fork lengths were estimated in cm by direct comparison of fishes to a 0.5 m cm-calibrated ruler attached at a perpendicular angle to the end of a 1.0 m PVC pipe carried out by each observer. Size data was used to calculate fish biomass according to Bohnsack and Harper (1988), and Bohnsack (unpublished manuscript). Weight-length relationships were calculated by fitting a regression line to the equation: $\log W = \log a + b \log L$, which is equivalent to the equation $W = aL^b$, where W is weight in grams, L is length in mm, and a and b are constants Data was obtained from CSJ, IR, PAL, CI, CD and CR.

Data was analyzed by means of bootstrapping analysis (Efron, 1982; Efron and Tibshirani, 1986). Each data set (individual replicate samples) was re-sampled 1000 times to generate a sampling distribution of the means of each parameter. The 0.025 and 0.975 percentile values of these distributions were calculated to test for significant differences ($\propto$=0.05) among sampling sites.

RESULTS

Epibenthic Communities

Coral species richness, measured as species/10 m-long transect, showed a linear trend to increase as we moved off degraded coasts (Figure 2a). Higher values were observed at CR (9.2±0.7 species). The lowest value was recorded at LB (3.3±0.6 species). There were highly significant differences among stations PP and LB, and the remaining stations. A similar trend was observed in the percentage of living coral cover (Figure 2b). Values fluctuated from 9.0±3.2% (LB) to 64.5±5.4% (CR). CR was significantly different from all other sampling sites. In addition, we can also separate stations in three general groups: low coral cover in highly degraded sites (PP, LB), moderate coral cover at moderately degraded sites (CSJ), moderately high coral cover at less degraded sites (IR,CI,CD) and exceptionally high coral cover at non-degraded offshore sites (CR). There were also significant differences in H'n between two basic groups (Figure 2 c) composed of high diversity sites located far from highly developed zones (CSJ, IR, CI, CD, CR) and low diversity inshore sites located close to highly developed zones and downstream of turbid coastal waters (PP, LB). The highest H'n value was observed at CD (1.8761±0.0530) and the lowest at LB (0.9608±0.2003), where opportunistic species (i.e., *Siderastrea radians*, *Erythropodium caribaeorum*) were dominant..

However, an inverse trend was observed when assessing the percentage of algal cover (Figure 2d). Algal cover values decreased with increasing distance from developed coasts and fluctuated between 43.3±5.4% at CR, the farthest sampling site, and 80.5±3.5% at LB.

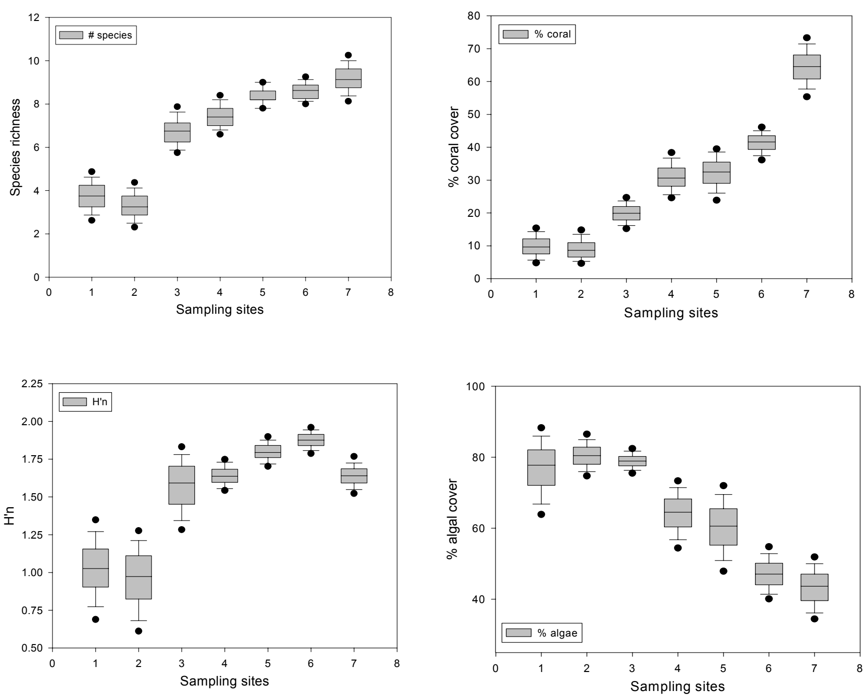

FIGURE 2. Box and whisker plots after bootstrapping analysis (n=1000 replicates) for the coral reef epibenthic community data based on average values/10 m-long transect (from top left): a) species richness; b) percentage of living coral cover; c) H'n; d) percentage of algal cover. Study sites are arranged in each plot from highly degraded and close to shore coral reefs (i.e., PP), to less degraded, offshore reefs (i.e., CR). 1=PP, 2=LB, 3=CSJ, 4=IR, 5=CI, 6=CD, 7=CR.

Reef Fish Communities

Although coral reef fish species richness, measured as the number of species/15 min. sampling station, showed also a gradual increase as we moved off degraded coasts, it was non-significant (Figure 3a). The lowest value was observed at CSJ (13.9±1.6 species) and the highest at CR (18.0±1.1 species). A similar trend was observed in fish abundance per station (Figure 3b). PAL was significantly different from offshore sites CI, CD, CR, where fishes were more abundant, but not different from inshore sites (CSJ, IR). Data from IR is highly skewed and showed a high variation due to the presence of occasional large schools (>500) of acanthurid fishes. The lowest fish abundance was observed in PAL (49.5±6.8 fishes/station), which is frequented by recreational spearfishermen. CD showed the highest abundance value (110.0±21.3 fishes/station). There were no significant differences in H'n among sampling sites (Figuere 3c), although H'n was slightly lower at the degraded CSJ (2.0832±0.1660). The highest value was observed at PAL (2.2669±0.0900). Total fish biomass/station was also significantly lower in PAL (1413.1±232.5 g/station) than in the other sampling sites (Figure 3 d), which may also suggest a severe overfishing effect. There were no significant differences in total fish biomass among the remaining sites. The highest value was observed in CSJ (4569.4±2295.5 g/station). There were non-significant differences in total fish biomass of fishery target species among sampling sites (Figure 3e). However, PAL also showed the lowest value (5.3±1.1 g/station), which represents 0.38% of the total fish biomass for that sampling site (Figure 4). The highest value was documented at CR (11.4±3.7 g/station), which also represented 0.38% of the total fish biomass for that site. Both, PAL and CR showed the highest proportion of biomass/station of target fishes with 0.38% (Figure 4). The lowest value was observed at IR (0.18%).

DISCUSSION

Our study showed that there are significant differences in the structure of coral reef epibenthic and fish communities through an anthropogenic environmental stress and fishing pressure gradient. There is a trend towards a better ecological condition of offshore essential fish habitats. This differences are more dramatic in sessile epibenthic communities. It has been previously documented that most inshore coral reef epibenthic communities in northeastern Puerto Rico are highly degraded (Mckenzie and Benton, 1972; Goenaga and Cintrón, 1979; Goenaga and Boulon, 1992; Hernández-Delgado, 1992; Hernández-Delgado, in preparation). Degradation ahs been the result of major factors, including: filamentous algal overgrowth and chronic coral mortality associated to damselfish (Pomacentridae) territorial behavior (Hernández-Delgado and Alicea-Rodríguez, 1993; Vicente, 1993; Hernández-Delgado, in preparation), bleaching related mortality of corals (Goenaga et al., 1989; Goenaga and Canals, 1990), eutrophication (Goenaga, 1991), increased water turbidity and sedimentation rates (Goenaga 1986, 1988), dredging and marina development (Hernández-Delgado, 1992), military bombing activities (IDEA, 1970; Rogers et al., 1978) and uncontrolled recreational activities. All of these factors have historically contributed to the development of an anthropogenic environmental stress gradient.

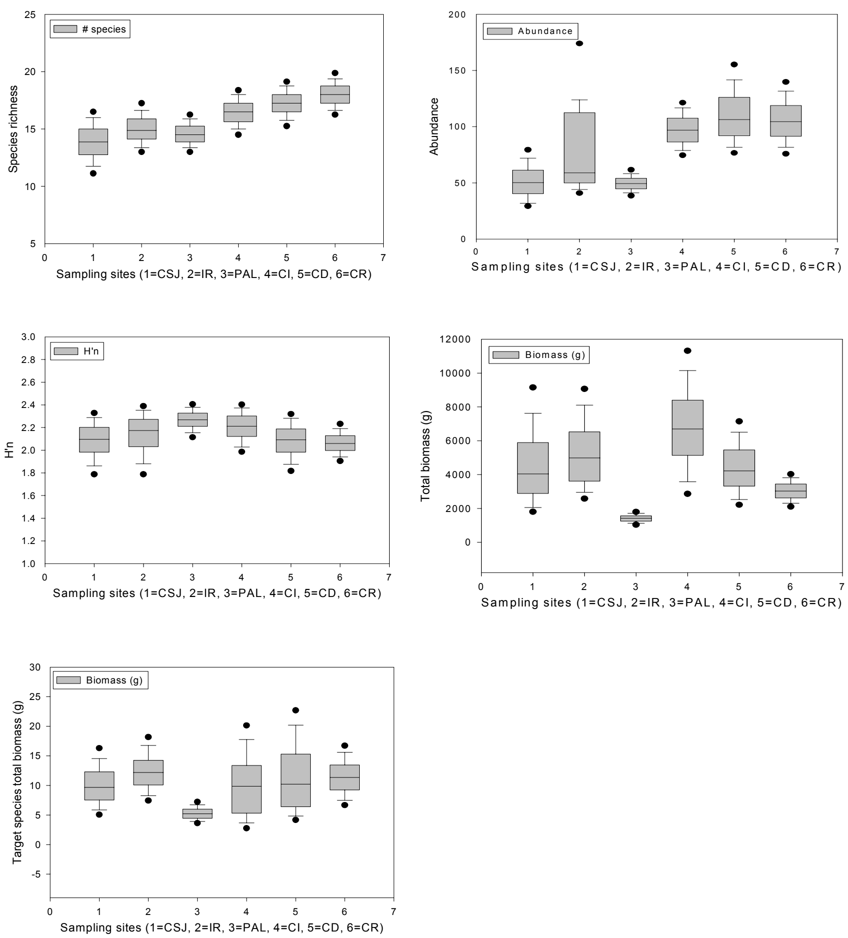

FIGURE 3. Box and whisker plots after bootstrapping analysis (n=1000 replicates) for the coral reef fish community data based on average values/15 min. long sampling station (from top left): a) species richness; b) abundance; c) H'n; d) total fish biomass (g); and e) total target fish species biomass (g).

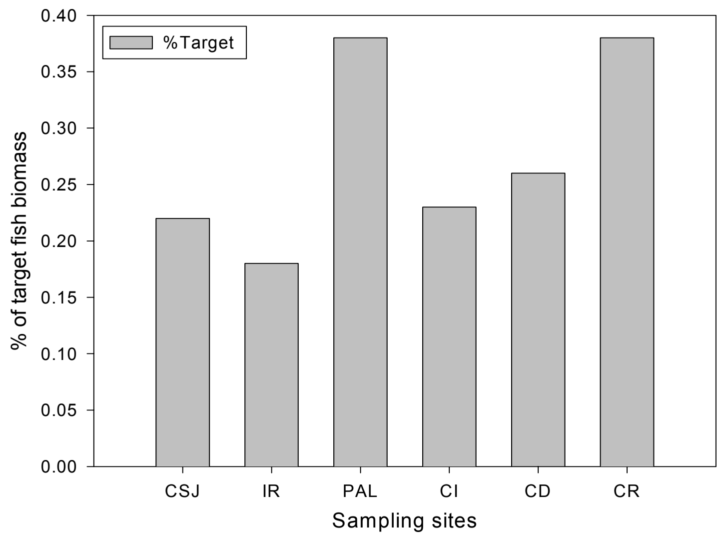

FIGURE 4. Proportion of target fish species biomass out of the total fish biomass per study site.

There are some important findings in our study. First, it becomes obvious that the farthest offshore is located the reef, in better health it is. That was the case of parameters which are considered indicatives of coral reef health, such as coral species richness, percentage of living coral cover and H'n. Coral reefs have been previously observed to be in better shape at higher distances from degraded coasts (Goenaga, 1988). It is also important to consider that there were no major differences in H'n between sampling stations because H'n alone is not a good indicator of ecological conditions. Although H'n was not significantly different in many of the sampling stations, the community structure was indeed different. Opportunist species (i.e., *Siderastrea radians*, *Porites porites*, *P. astreoides*, *Erythropodium caribaeorum*) were dominant at degraded sites PP and LB (data not shown). Sediment-resistant coral species such as *Siderastrea siderea* and *Montastrea cavernosa* were also dominant also in the highly sedimented CSJ. *Montastrea annularis* was the dominant coral in the remaining offshore stations. This is very important because the abundance of *M. annularis* has a strong correlation with increasing distance from developed coasts (Hernández-Delgado, in preparation). This species is probably the most important reef-building coral of the Atlantic and its presence provides a higher bio-constructional value to coral reefs. In the other hand, the percentage of algal cover decreased with increasing distance from developed coasts. This may reflect an eutrophication problem, which if combined with large herbivore overfishing (i.e., parrotfishes) and the high abundance of damselfishes, may have a long-term catastrophic effect in coral reef communities (Hughes, 1994).

Anthropogenic environmental stress gradients can also affect the structure of reef fish communities. However, changes can be more difficult to identify if we do not take into consideration the masking effects of overfishing. First, the lack of changes in reef fish species richness did not reflect the changes in the community structure. Acanthurids, territorial pomacentrids and parrotfishes were, in general terms, the most abundant groups (data not shown), but their dominance was higher near degraded sites (with higher algal cover). Planctivorous groups, generalist and piscivore predators were more frequently observed at less degraded, less overfished habitats. However, the abundance of the latter groups was reduced again at moderately degraded, but highly overfihed habitats, and at less degraded, but highly overfihed habitats. These differences in community structure were also reflected in the lower abundance values observed at the highly degraded CSJ and at the moderately degraded IR and PAL. The latter site also reflects severe overfishing effects in the significantly low abundance, total fish biomass and total fishery target species biomass. There were many species at PAL, but represented by only one or a few small-sized specimens. The other site which showed signs of overfishing, as previously demonstrated by Hernández-Delgado et al. (in press) was CR. Although CR showed a high abundance and high total fishery target species biomass, the total fish biomass was rather low. In other words, there was a high abundance of small-sized individuals. Both sites, PAL and CR, are highly frequented by SCUBA divers and recreational spearfishermen.

The overall situation of the study sites closer to degraded coasts is alarming. Four out of our seven study sites in the epibenthic study (PP, CSJ, CI, CD) and four out of our six study sites in the fish survey (CSJ, PAL, CI, CD) are located within the boundaries of Natural Reserves managed by the Puerto Rico Department of Natural and Environmental Resources. Another site (CR) is actually a candidate Marine Fishery Reserve (Hernández-Delgado et al., in press). All of them constitute part of the essential fish habitat of the Puerto Rican fishery stocks. However, anthropogenic environmental stress factors and overfishing have affected the community structure of both, epibenthic and fish communities in most of our study sites, including those within the boundaries of Natural Reserves. This suggest that present management measures are not adequate to prevent the depletion of fishery stocks and the continuous loss of essential fish habitat.

The loss of critical habitats may have significantly negative effects on fishery stocks. Carpenter et al. (1981) showed that there were strong positive correlations between living coral cover and diversity, and abundance of reef fishes. Gladfelter and Gladfelter (1978), Carpenter et al. (1981) and Galzin et al. (1994) also found that fish biomass increased with structural heterogeneity of reef substratum. In addition, Doherty et al. (1997) found that a catastrophic loss of coral cover on the Great Barrier Reef caused a great reduction in fish recruitment, suggesting that any significant change in epibenthic communities composition may affect fish communities. However, little is known about the direct and indirect ecological effects of declining populations of reef fishes on factors such as settlement, recruitment, survival, tissue regeneration and bioerosion rates of reef-building corals, processes which are vital for structuring and maintaining coral reef epibenthic communities. According to Bohnsack (1993), this lack of studies becomes a problem due to the lack of long-term monitoring studies on coral reef fish populations, multi-disciplinary studies on reef problems, experimental studies, valid scientific controls (i.e., marine fishery reserves), and because sometimes fishing effects could be masked by other anthropogenic factors.

CONCLUSIONS

The presence of an anthropogenic environmetal stress gradient in coral reef communities can change the structure of coral reef epibenthic and fish communities. Degradation is stronger at inshore habitats, which showed lower coral species richness, percentage of living coral cover and species diversity. These habitats are also characterized by having higher algal cover, and low abundance and diversity of reef fishes. Offshore, less degraded habitats are characterized by higher coral species richness, percentage of living coral cover and species diversity. These habitats are also characterized by having lower algal cover, and high abundance and diversity of reef fishes. However, overfishing effects should always be taken in consideration since they can mask the expected results for less degraded habitats (i.e., higher fish species richness, abundance, biomass and diversity).

It is also alarming that the Espíritu Santo River, Las Cabezas de San Juan and La Cordillera Natural Reserves are showing unequivocal signs of severe anthropogenic degradation, which has undergone undocumented for years. There is an immediate need for the establishment of management measures to prevent further increases in sewage pollution, sedimentation and thus, water quality degradation. In addition, our data suggest that one of the best management alternatives would be establishing a network of small Marine Fishery Reserves (=no take zones) at Cayo Diablo, Palominitos Island, Cayo Icacos and at the western coast of Culebra Island to help restore depleted fish stocks.

Additional studies are required to expand our understanding of which are the relationships between the ecological conditions of coral reef epibenthic and fish communities, how can anthropogenic environmental stress gradients can affect these relationships and which effects, if any, can these relationships have in the distribution of commercially-important fish species. We also have a challenge to protect, as soon as possible, healthy essential fish habitats. But, we also have the challenge to protect and restore highly degraded essential fish habitats before time is over.

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