Tourism and Coral Reef Health in the Exuma Cays Land and Sea Park

El Turismo y Salud de los Arrecifes de Coral en el Exuma Cays Land and Sea Park

Le Tourisme et la Santé des Récifs Coralliens dans les Exuma Cays Land and Sea Park

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ABSTRACT

Quantitative and qualitative assessments of fish and benthic community structure are being used in the development of a long-term monitoring programme for the Exuma Cays Land and Sea Park (ECLSP). Combined with estimates of critical resource thresholds for coral reef habitats, this monitoring promises to contribute to more effective management of the ECLSP, which in turn will help minimize future anthropogenic impacts and improve the health and resilience of critical habitats.

Fourteen sites, across four habitat types – deep forereef (> 10 m), shallow forereef (< 10 m), fringing, and channel reefs, were selected based on relative potential impacts from several human activities such as fishing, diving, and coastal development. Species density and biomass data were collected for fish species observed during belt transect surveys. Relative abundance of commercial fish species and invasive lionfish was assessed using transect and timed roving diver surveys. Dominant benthic cover was estimated using point-intercept sampling within 1-m^2 quadrats. Species lists of major taxa were also compiled for each quadrat.

Preliminary data analyses of fish species abundances using Analysis of Similarity (ANOSIM) and multidimensional scaling (MDS) revealed temporally stable fish communities that varied by habitat type. The greatest differences in fish community structure were between two of the forereef sites outside of the Park and the rest of the forereef sites. ANOSIM and MDS analyses show that benthic community structure and biodiversity composition varied significantly across sites and reef types. Deeper and shallow forereefs differed significantly, and both were highly distinct from fringing and channel reefs, which were not significantly different. Forereef sites were dominated by macroalgae; fringing and channel reefs were dominated by combinations of corals, sponges, and turf algae. Analyses detected no obvious impacts from diving and development pressures on reefs, but statistical power remains poor given the number of sites and the duration of the sampling period.

KEY WORDS: Coral reefs, fish community structure, benthic community structure, anthropogenic impacts

INTRODUCTION

Coral reefs are one of the most productive and diverse ecosystems on Earth and provide critical ecosystem functions and services to coastal communities (Maragos et al. 1996). Yet coral reef ecosystems are in crisis from a range of anthropogenic impacts that occur at both global and local scales. As of 2008, 19% of coral reefs globally have been lost and 35% are threatened (Wilkinson 2008), though major losses in the Caribbean appear to pre-date and be more extensive than those in the Indo-Pacific (Gardner et al. 2003, Pandolfi et al. 2003, Bruno and Selig 2010). Threats to Bahamian coral reefs include overfishing, climate change, eutrophication and pollution, and natural disasters (e.g., hurricanes and coral diseases), and these anthropogenic impacts appear to play significant roles in determining community structure and other changes in biodiversity (Harborne et al. 2008).

Marine protected areas (MPAs), especially no-take reserves, are often used as a precautionary approach to ecosystem management and are designed to manage, conserve, and replenish ecologically and economically important natural resources (Harborne et al. 2008). The Exuma Cays Land and Sea Park (ECLSP), established in 1958 and designated a no-take area in 1986, is the oldest reserve in The Bahamas, protecting 456 square kilometers of marine and terrestrial habitats (Figure 1). Among the best-studied aspects of marine biodiversity in the park are the effects of marine reserve protection on reef-fish populations and assemblage structure. Dahlgren (2004) reported that larger grouper species such as Nassau grouper (*Epinephelus striatus*) have greater biomass inside the park compared to outside. Additional studies have confirmed that reef fish communities within the ECLSP have a greater proportion of higher-level predators, both relative to their immediate non-park vicinity (Chapman et al. 2006, Mumby et al. 2006a, Mumby et al. 2006b, Harborne et al. 2008, Lamb and Johnson 2010) and the Caribbean at large (Stallings 2009, Ward-Paige et al. 2010). The abundance of higher-level predators like *E. striatus* has also been linked to reduced biomass of the invasive lionfish (*Pterois volitans*) within ECLSP boundaries. Invasive lionfish, with a more varied generalist diet than in their native range (Morris and Akins 2009, Cure et al. 2012), are a serious concern to marine resource managers due to their significant impacts on fish and invertebrate recruits to reef habitats (Albins and Hixon 2008).

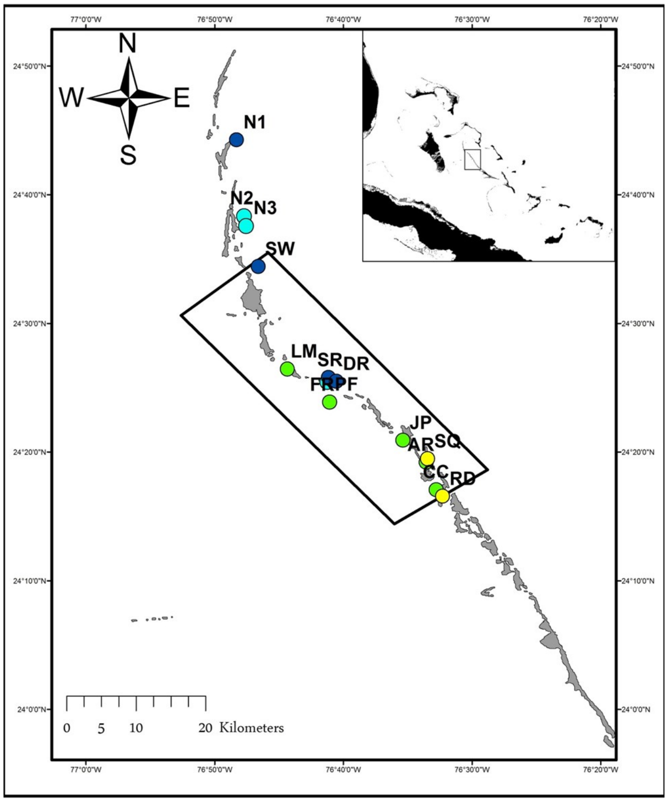


Figure 1. Map of The Bahamas and the Exuma Cays Land and Sea Park showing the location of the 14 survey sites. 11 sites are located within the Exuma Cays Land and Sea Park boundaries (bordered in black) and three sites are located north of the Park. Sites are colour coded according to reef type: green = channel reef, yellow = fringing reef, light blue = shallow forereef, dark blue = deeper forereef.

With respect to how changes in fish community structure inside the Exuma Park can affect benthic community patterns, a series of studies by Mumby, Harborne, and colleagues (Mumby et al. 2006a, Mumby et al. 2007, Harborne et al. 2008, Mumby and Harborne 2010) have shown the relationship between such factors as piscivorous fish biomass, herbivorous fish assemblage structure and grazing pressure, seaweed abundance and assemblage structure, and the recruitment and growth of corals. Since it is difficult to infer such interactions from assemblage and community structure over wider areas, especially across seascapes that may vary biophysically and in terms of human activities, conservation planners and resource managers often rely on habitat structure and knowledge of species-habitat relationships as proxies for ecological communities. Harborne and colleagues (2008) tested the underlying proxy assumption that assemblages in one kind of habitat (e.g., *Montastraea*-dominated forereef) in one place are similar to the assemblages in the same kind of habitat elsewhere. Although species assemblages differed distinctly among habitat types, significant assemblage differences were also found in the same habitat type among major Bahamian islands, suggesting some limitations in the consistency of species-habitat relationships and the utility of the habitat proxy at some spatial scales. These studies collectively highlight the possible complexity of reef community structure and trophic interactions within the park.

Despite this work on how the ECLSP functions as a reserve, the extent to which anthropogenic impacts affect critical habitats within the park remains poorly understood. In order to address this gap, we are developing a long-term monitoring program with core support from a Global Environment Facility (GEF) grant to the Bahamian government. In addition to generating baseline monitoring data for longer-term comparisons, key objectives of this three-year pilot project include building reef monitoring capacities within The Bahamas and estimating critical resource thresholds in response to local threats from park users and nearby land development. A well-developed and maintained monitoring programme, capable of detecting anthropogenic changes over time, may improve the effectiveness of park management, which may help enhance the health and resilience of critical habitats.

METHODS

Study Design and Site Selection

Surveys to date for this project have been conducted at a total of 14 sites within and outside of the Exuma Cays Land and Sea Park (ECLSP) from Nov. 2010 – Sept. 2012, and will continue through 2013 with current funding. Most sites were sampled at two or three times during the study period, but two sites (Parrotfish and Danger Reefs) – intended as case studies of seasonal change – were surveyed seven and six times, respectively. Results presented here include data from all seven surveys through Sept. 2012 for fishes, and six surveys from March 2011 through Sept. 2012 for benthic communities. Fourteen sites, across four coral reef habitat types – deep forereef (> 10 m), shallow forereef (< 10 m), fringing, and channel reefs, were selected based on the relative impacts of several human activities. Each site has been assigned to a threat level (low, low-medium, medium, medium-high or high) associated with the following threats: diving or snorkelling, chronic eutrophication from development, ship groundings from poor navigation, and fishing activity (Table 1). To facilitate comparisons of the effects of resource protection, surveys were also conducted at three forereef sites outside of the Exuma Park boundaries – BBP NM1, NM2 and NM3 (Figure 1).

Fish Surveys

Three types of surveys were used to assess intra- and interspecific differences in fish density and community structure among reef types. Quantitative assessments of fish populations and community structure were assessed using a total of eight belt transects (30 x 2 m) at each site.

Table 1. List of survey sites by habitat type and perceived level of anthropogenic impacts.

Site Name	Site Code	Latitude (°N)	Longitude (°W)	Reef Type	Threats from fishing activity	Threats from diving & snorkeling	Threats from chronic eutrophication from development	Threats from poor navigation or ship groundings
Jeep Reef	**JR**	24.34862992	-76.58958884	Channel Reef	Medium-high	Medium-high	Medium	Medium
Lobster Mountain	**LM**	24.44108783	-76.73928211	Channel Reef	Medium-high	Medium	Medium	Medium
Conch Cut	**CC**	24.2845954	-76.54638154	Channel Reef	Medium-high	Medium	Low	Low
Friday's Reef	**FR**	24.39812365	-76.68453531	Channel Reef	Low	Low	Low	Low
Airplane Wreck	**AR**	24.32009371	-76.5593855	Channel Reef	Medium	Low-medium	Low-medium	Low
Shark Reef	**SR**	24.42992569	-76.68605222	Deeper Forereef	Medium	Low	Low	Low
Danger/Amberjack Reef	**DR**	24.42503546	-76.67597765	Deeper Forereef	Medium-high	Medium	Low	Low
BBP North M1	**N1**	24.737848	-76.805005	Deeper Forereef	High	High	Medium	Low
Shroud Cay Wall	**SW**	24.5736899	-76.77691781	Deeper Forereef	Medium-high	High	Low	Low
Parrotfish Reef	**PF**	24.42396106	-76.68734367	Shallow Forereef	Medium	Medium	Low	Low
BBP North M2	**N2**	24.63888479	-76.79527387	Shallow Forereef	High	Medium	Medium	Low
BBP North M3	**N3**	24.62630482	-76.79250631	Shallow Forereef	High	Medium	Medium	Low
Sea Aquarium	**SQ**	24.32473404	-76.55771779	Fringing Reef	Medium	High	Medium	Low
Rocky Dundas	**RD**	24.27614707	-76.53802448	Fringing Reef	High	Medium	Low	Medium

Within each belt transect, all fish were identified, counted, and their size estimated to the nearest centimeter. The other surveys consisted of multiple ten-minute roving diver surveys at each site in which all species observed were recorded, as well as the abundance and size of several key species, including large groupers, lionfish, and sharks. This survey was designed to assess species richness as well as contribute additional population abundance data for key species that are difficult to assess in traditional belt transects. In total, 507 belt-transects and 96 timed roving diver surveys were conducted.

Benthic Surveys

Benthic cover at each site was assessed by conducting point-intercept surveys using $1m^2$ quadrats. Points were visually aligned via orthogonal lines-of-sight through 16 grid intersections per quadrat. Approximately 40 quadrats per site were sampled (for a target of 640 points/site), with surveyors deploying quadrats haphazardly a minimum of 1 meter distance from previous quadrats. Maximum vertical relief was visually estimated under each quadrat as the vertical difference between high and low points. When quadrats fell against near vertical walls, maximum relief was estimated orthogonally to the quadrat rather than vertically. Observation depth was also measured at the center of each quadrat. Species lists (including morphospecies, genera, and higher order groupings) were compiled for major taxa within each quadrat, including algal (seaweed) genera or functional group; scleractinian and hydrocoral species; gorgonian species or genera; sponge species, genera, or functional group; and species and genera of other sessile invertebrates such as anemones, corallimorphs, zoanthids, hydroids, and tunicates. Photographs were taken of each surveyed quadrat for reference and archival purposes.

Statistical Analysis

Similarities in fish and benthic community structure and biodiversity composition across reef types were analyzed using the Analysis of Similarity (ANOSIM) procedure implemented in PRIMER 6 software (Clarke and Gorley 2006). Multi-dimensional scaling (MDS) plots were also used to visualize similarities among sites. SIMPER analysis was also used to determine which species contributed most to observed differences. Benthic community structure analyses utilized percent cover of several relatively coarse categories (i.e., fleshy macroalgae, cyanobacteria, turf algae, crustose coralline algae, coral, gorgonians, sponges, other invertebrates, and other substrates), whereas biodiversity composition focused on presence/absence analyses of finer functional or taxonomic resolution of these categories. Although less important for non-parametric analyses, all percent cover data was transformed via the Arcsin transformation, and results were compared and found to be qualitatively similar across this and further square- and fourth-root transformations in PRIMER 6.

RESULTS

Fish Community Structure

Fish communities at the sites sampled were temporally stable, but varied by habitat type and to a lesser extent by location. Sites showed grouping according to habitat type, with the majority of deep forereef sites forming one grouping, shallow forereef sites forming a second grouping, fringing reefs forming a third major grouping and channel reefs forming a fourth grouping (Figure 2). Within habitats, fish communities of deep forereefs were most similar (Average Bray-Curtis Similarity = 72.34%) followed by channel reefs (72.31%) and shallow forereefs (72%) and fringing reef sites (71.39%).

Average Bray-Curtis dissimilarity pairwise comparisons among habitats revealed that fish communities were most dissimilar between deep forereef versus fringing reefs (41.57%) and least dissimilar between channel and fringing reefs (28.95%). SIMPER analyses indicated that no species contributed more than 7% to the observed differences between deeper forereef, fringing and channel reef habitats. A total of seven species contributed more than 4% to observed differences – bluehead wrasse (*Thalassoma bifasciatum*), French grunt (*Haemulon flavolineatum*), creole wrasse (*Clepticus parrae*), fairy basslets (*Gramma loreto*), blue chromis (*Chromis cyanea*), blackcap basslets (*Gramma melacara*) and sergeant major (*Abudefduf saxatilis*). For example, the difference between deep forereefs and fringing reefs can be attributed to high densities of creole wrasse 7% (of total difference), French grunt (5.11%), and bluehead wrasse, fairy basslet and blackcap basslet all contributed > 4% to observed differ-

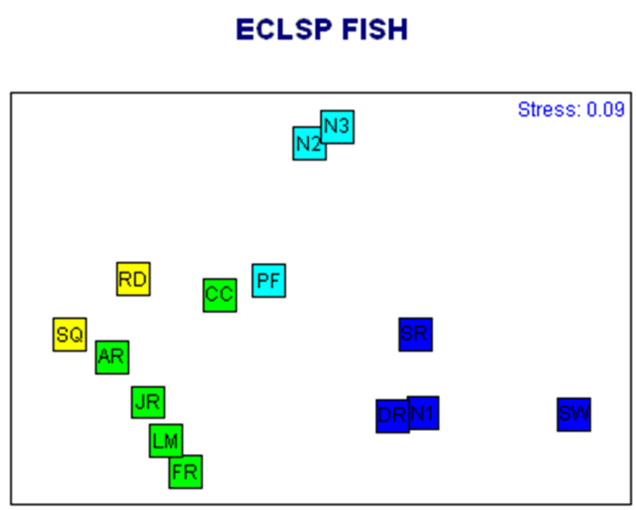


Figure 2. Multidimensional scaling (MDS) plot showing similarities in fish community structure averaged from data collected between November 2010-September 2012 and stratified by reef habitat type: green = channel reef, yellow = fringing reef, light blue = shallow forereef, dark blue = deeper forereef.

ences, with French grunts and bluehead wrasse being more abundant at fringing reefs and creole wrasse and basslets more abundant at deep forereefs (Figure 3). The average dissimilarity in fish community structure among habitats can be seen in Table 2.

Perceived levels of anthropogenic impacts including fishing and diving were greatest at the three forereef habitats outside of the Park – BBP NM1, NM2 and NM3 and lowest at Friday's Reef – a channel reef in the southern part of the Park (Figure 4). Within ECLSP boundaries, the fishing impacts were highest at Rocky Dundas. However, most sites within the Park showed medium to medium-

Table 2. Comparisons of Average Bray-Curtis dissimilarity analyses across sites. ANMOSIM analyses was used to determine significant differences (p = 5%); np = analyses that could not be performed due to insufficient sample sizes. Statistically significant results are denoted with an asterisk.

	Channel Reef	Fringing Reef	Shallow Forereef
Channel Reef	np	np	np
Fringing Reef	28.95	np	np
Shallow Forereef	36.22*	35.51	np
Deep Forereef	38.05*	41.57	37.97*

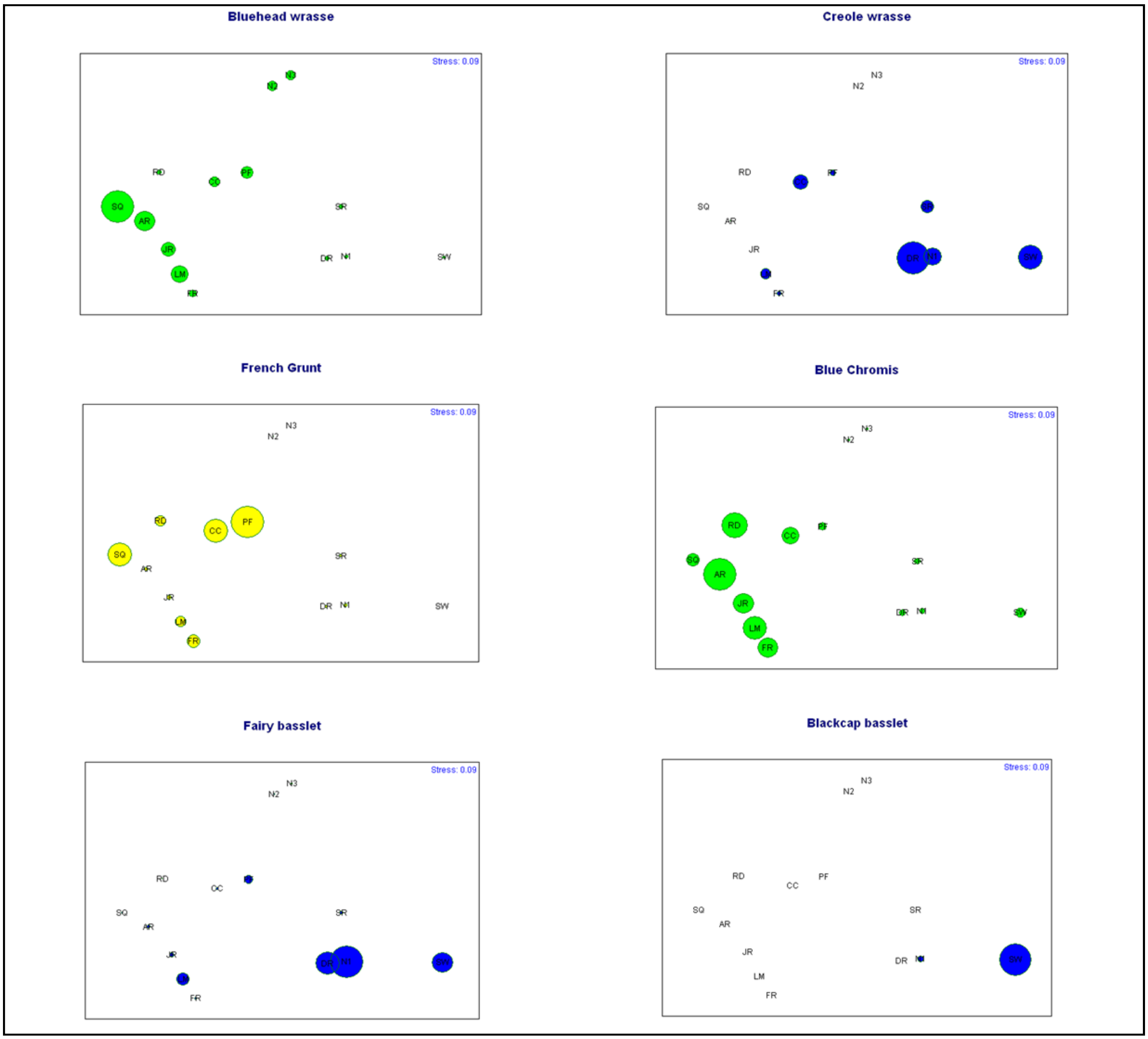


Figure 3. Relative population sizes of fish species, overlaying the MDS plot of fish community structure among habitats.

high levels of impact due to fishing. Perceived impacts of diving on fish community structure were highest within ECLSP boundaries. Heavily impacted sites included two deep forereef sites – Danger/Amberjack Reef and Shroud Wall and one of the fringing reef sites – Sea Aquarium. Diving impacts were also lowest at two sites within ECLSP boundaries – Friday's Reef and Airplane Wreck. Overall, shallow forereefs showed the greatest variability among sites – (Average Bray-Curtis dissimilarity = 32.3%) between Parrotfish Reef and two sites outside the ECLSP – BBP NM2 and NM3. The dissimilarity was primarily due to French grunts (12.7%), Caesar grunts (6.6%), Longjaw squirrelfish (6.7%), and Schoolmaster snapper (6.17%). Species of major fishery importance e.g., Nassau grouper only contributed to 0.85% of the observed difference. There was no significant difference in the mean abundance of Nassau grouper and lionfish observed during transect ($60m^2$) versus timed roving diver surveys. Mean abundances of Nassau grouper and lionfish from transect and roving diver surveys varied across habitats with both species being more abundant and deeper forereef and fringing reef habitats and least abundant at the shallow forereef site outside the park – BBP NM3 (Figure 5).

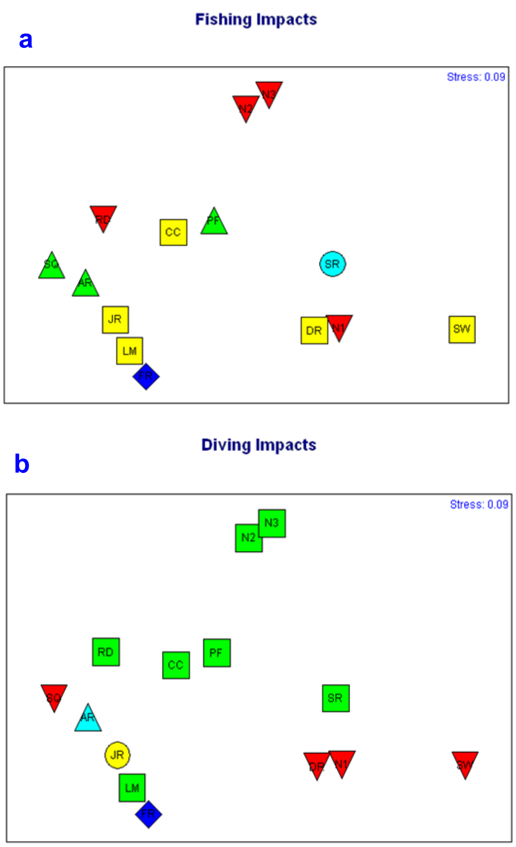


Figure 4. MDS plot of perceived anthropogenic impacts on fish community structure across sites. Sites with low impacts = dark blue, low-medium impacts = light blue, medium = green, medium-high = yellow, and high = red.

Benthic Community Structure & Biodiversity

Parrotfish Reef experienced statistically significant temporal variation in community structure (Bray-Curtis average dissimilarities of 29 – 34%, $p = 1.1\%$, with DIVER as a nested significant factor within SURVEY period), whereas Danger Reef experienced marginally significant variation (average dissimilarities of 25 – 31%, $p = 5.1\%$) given a conventional significance threshold. At both sites, contributions to dissimilarity of benthic community structure across survey periods tended to be due to changes in the percent cover of crustose coralline algae (CCA), gorgonians, sponges, other invertebrates, and non-living substrates.

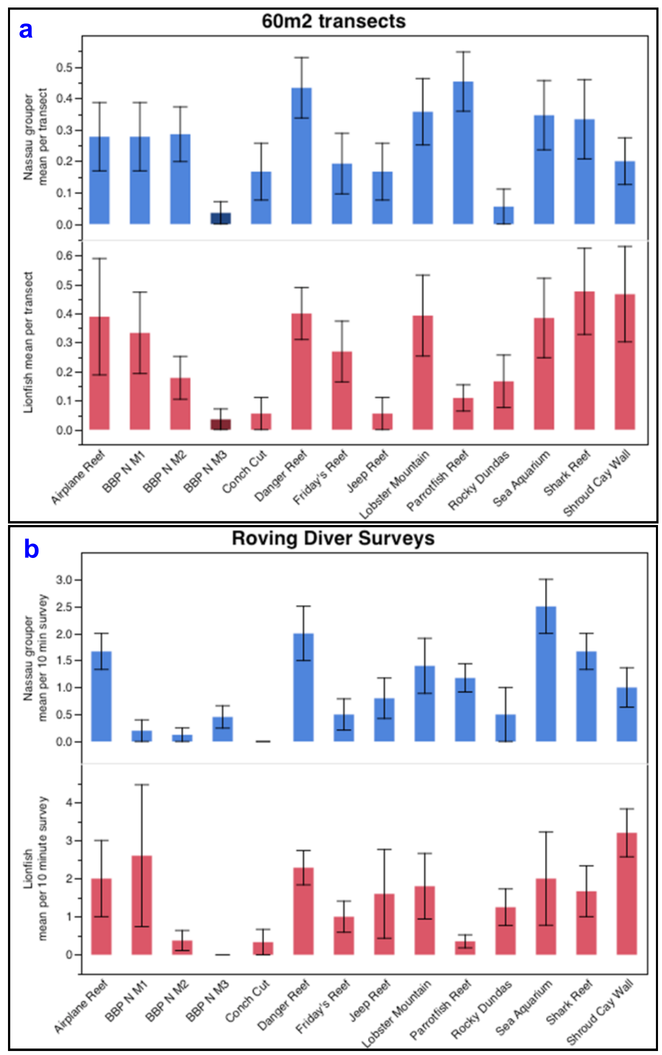


Figure 5. Comparisons of the mean abundance of Nassau grouper (*Epinephelus striatus)* and red lionfish (*Pterois volitans)* across habitats assessed from a) 60 m^2 transect surveys (n = 507) and b) ten-minute timed roving diver surveys (n = 96). Error bars are reported as one standard error from the mean.

Compared to the modest seasonal variation within sites noted above, benthic communities diverged more consistently and significantly among sites (Global R = 0.291, p = 0.1%, with DIVER as another significant factor) and reef types (Global R = 0.24, p = 0.1%), with both shallow and deeper forereefs being significantly different from each other and from channel and fringing reefs (all pairwise differences, p = 0.01%), but channel and fringing reefs appearing similar (p = 27.9%). In pairwise differences, nearly all sites were significantly different from other sites in terms of community structure (p = 0.1 – 2.5%), except for Friday's Reef and Jeep Reef (both channel reefs, p = 8.7%), results that are echoed in the MDS visualization (Figure 6). The greatest Bray-Curtis Dissimilarities (~ 47 – 59%) were found between individual channel or fringing reefs and individual forereefs, while the smallest dissimilarity (~ 25%) was found between a channel and fringing reef.

Geographic proximity among reefs appears to be secondarily important, after habitat type, to certain patterns of community structure variation. For example, BBP NM2 and NM3 cluster together in terms of community similarity as well as geographical space, as do Danger and Parrotfish Reefs, despite their differences in habitat type. Other anthropogenic factors, such as categories of diving/snorkeling intensity and proximity to development appear to be relatively unrelated to currently observed differences among community structure (Figures. 7 and 8). Patterns of variation in biodiversity composition were qualitatively similar in all cases to those of community structure, so we do not report them in detail here.

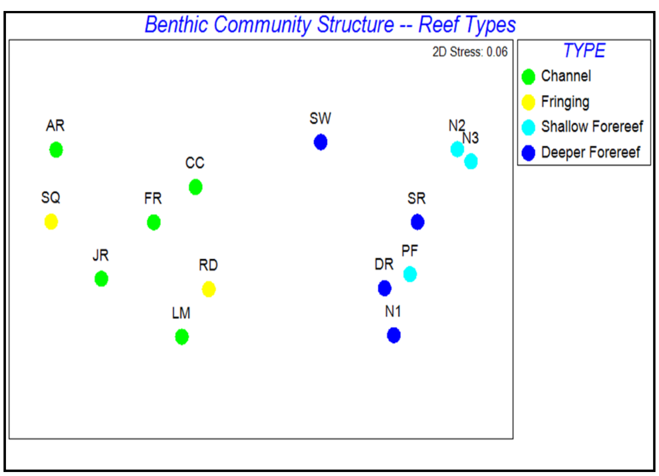


Figure 6. MDS plot showing similarities in benthic community structure averaged from data collected between March 2011 and September 2012 and stratified by reef habitat type: green = channel reef, yellow = fringing reef, light blue = shallow forereef, dark blue = deeper forereef.

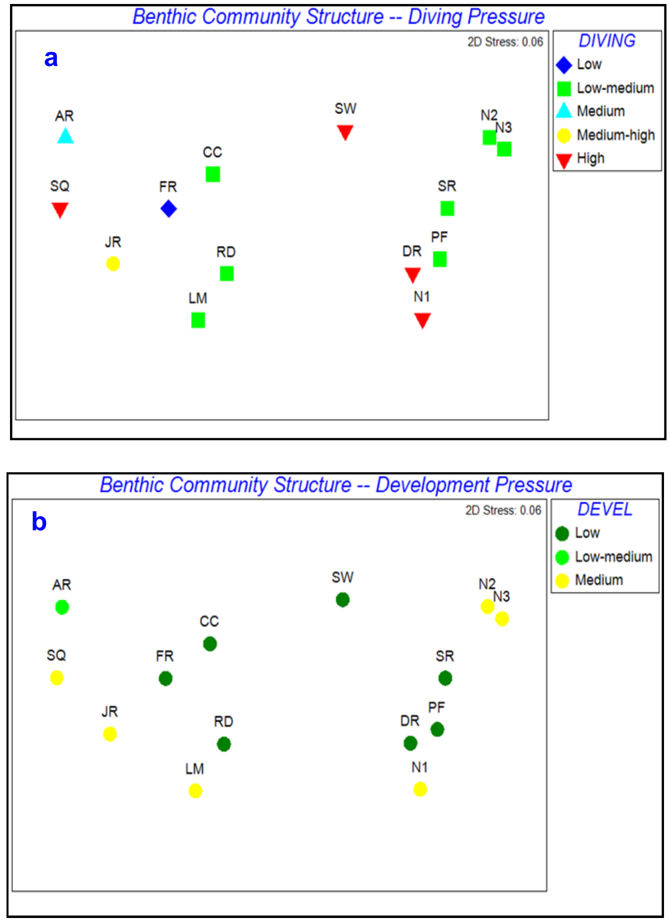
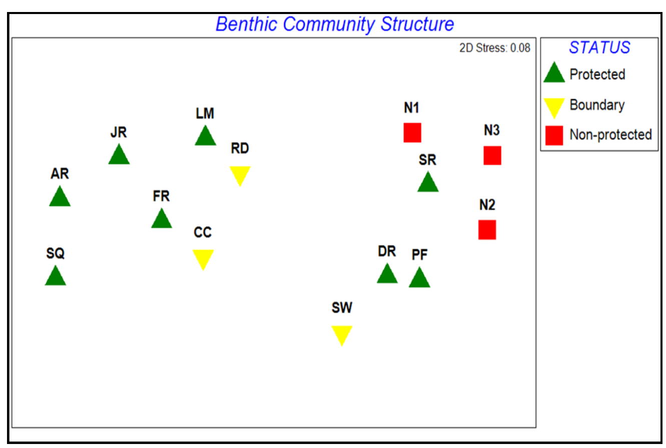


Figure 7. MDS plot of perceived anthropogenic impacts from from a) diving and b) development pressure on benthic community structure across sites.



DISCUSSION

Fish Community Structure

Among reef sites, differences in fish communities were based on reef type and location, but the observed differences were subtle and no single species was responsible for much of the observed differences. The effect of the park protection on reef fish communities was not consistent, with two of the sites outside the park showing strong differences from sites of the same habitat type within the park (BBP NM1 and NM2), but the third site outside the park grouped with other deep forereef sites within the park. Higher similarity of sites in different habitats in close proximity to each other than those in similar habitat types farther away also indicates that fish communities also vary by geography, possibly due to differences in recruitment, differences in the distribution of nursery habitats, or even human impacts that vary within the Park (Dahlgren et al. 2006, Harborne 2008).

During the third year of this project, issues related to explaining some of the observed structure in reef fish communities will be further examined, including a more detailed analysis of populations of key species that will be identified based on data from the first two years of the project, as well as correlations between reef fish communities (and/or populations of key species) with benthic community characteristics and predicted levels of human impact. Further temporal comparisons over an extended time period will also determine if the pattern of temporal consistency remains or if there are changes over time.

Benthic Community Structure & Biodiversity

Baseline benthic monitoring to date has characterized differences in community structure and biodiversity composition across sites and habitat types. These two multivariate attributes, as currently sampled, however, do not appear to be particularly sensitive to variation in anthropogenic threats, implicitly raising the question of whether these local threats are of relatively little importance in this relatively lightly populated, tidally flushed central Bahamian reef system, or whether more sensitive measurements need to be added to the current monitoring approach. New approaches might include better characterization and monitoring of coral bleaching, disease, bioerosion, and coral colony size structure. Tissue samples and genetic expression assays could be used to document changes in physiological stress prior to visual changes in phenotypes. Similarly, periodic collections of seaweed and analyses of stable isotopes could also reveal biologically meaningful changes in nitrogenous pollution associated with coastal development.

Such monitoring options, of course, need to be considered in light of management needs, financial costs, and staff technical capacities within the Bahamas National Trust (BNT) and its partner organizations. Training of BNT staff in field monitoring techniques has been an important objective of this project, but given the BNT's relatively small staff size and the likelihood of periodic staff turnover, further capacity building within the agency and among its partners remains a high priority. In particular, further emphasis on the development of Bahamian relevant training materials, more explicit adoption of a "training of the trainers" approach, and the development of further financial support to expand the national base of skilled reef monitoring trainees are recommended steps that should contribute to greater monitoring and management effectiveness in Bahamian MPAs.

ACKNOWLEDGEMENTS

We wish to thank Nicola Smith, Christopher Dunkley, Ancilleno Davis, Kristal Ambrose, Kathleen Sullivan-Sealy, and Elton Joseph for providing field assistance. Special thanks to ECLSP staff – Andrew Kriz and Henry Haley – for their continued support of the monitoring research team. This project is being funded by the Global Environment Facility (GEF) Full Size Project (FSP) component 2.4(3) through the United Nations Environment Programme with in-kind and co-financial support from the Bahamas National Trust, the Bahamas Environment Science and Technology (BEST) Commission, the Department of Marine Resources, The Nature Conservancy, the Perry Institute of Marine Science, and the American Museum of Natural History.

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