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Characterization of tropical near-shore fish communities by coastal habitat status on spatially complex island systems

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Synopsis

We present a protocol for characterizing near-shore fish habitat as well as fish communities for Andros Island, Bahamas, a complex coastal-reef island system. Benthic assessments and beach seine surveys were carried out at sites varying in coastal and benthic characteristics. Temporal variability affected fish community composition, indicating that attempts to characterize a fish community should include sampling evenly across tides, times of day, and seasons. Univariate and multivariate analyses revealed that each site harbored a unique fish community, with the greatest variability within each site attributed to seasonal changes. Measures of diversity (Shannon–Weiner Index and number of species) were markedly different at sites with varying coverage of seagrass and macro-algae and extents of disturbance. Total abundance of fishes was positively related to the percent of bare sand. We suggest that thorough sampling of coastal fish communities can be applied to comparative and long-term studies. This protocol for the characterization of complex island habitats can be applied to ecological studies aimed at understanding the responses of fishes to small-scale changes in coastal areas and habitat structure due to land use and shoreline alterations.

Introduction

Tropical near-shore soft-bottom habitats have long been acknowledged for providing habitat to many fish species, and coral reef fishes in particular (Colton & Alevizon 1983, Shulman & Ogden 1987, Mateo & Tobias 2001). The structural complexity of soft-bottom benthic biota, which is associated with the seagrass and benthic macroalgae, may contribute to a high-quality habitat that provides fish with food sources and refuge from predation and environmental stresses (Roberts & Ormond 1987).

An important issue is devising a long-term sampling protocol that can best capture small site-to-site differences in coastal fish communities, while elucidating which habitat characteristics most influence fish distribution. Near-shore soft-bottom habitats are large, spatially complex, and difficult to characterize (Curran & White 1995). Habitat mapping in tropical marine systems has, unfortunately, focused on coral reefs and reefal habitats that are spatially more discrete than the large expanses of sand, seagrass and algae (Almeda-Villela et al. 2002), which often comprise the largest areas available to fishes on island bank systems. Since habitat mapping is often incorporated into marine protected area design (Recksiek et al. 2001), modeling of fish production (Appeldoorn et al. 2001) and environment impact assessments for development planning and beach restoration (Lindeman et al. 2000), it is necessary to quantify site-to-site variability and heterogeneity of habitats and their influences on fish communities. A simple quantitative protocol for near-shore habitat and fish assessment is critical for long-term ecological studies for rapidly developing and changing landscapes.

The first objective of this study was to better define the sampling protocol needed to characterize a site by addressing issues of sampling effort and natural temporal variability. The dependent variables of total abundances, species abundances, Shannon–Weiner diversity and number of species were examined at different tidal states, times of day, and seasons to determine if and how fish communities varied temporally. This first objective was aimed at elucidating the nature of natural temporal variability and determining how to address this variability when trying to characterize a site's fish community.

The second objective of this study was to correlate patterns in fish communities at different sites with coastal and benthic characteristics of those sites. Four beach locations along central Andros were selected as sample sites. We hypothesized that features of fish communities (number of individuals, number of species and diversity) would be positively correlated to coverage of the benthic flora. Since fish community structure has been shown to be a good indicator of environmental responses of coastal habitats to changes in land cover and development patterns (Mumby et al. 2004), we also speculated that habitats exposed to varying levels of erosion-inducing exotic plants and physical restructuring of the shoreline, would vary in their fish community composition. Specifically, we predicted that fish diversity and abundances would be negatively correlated to increases in these coastal characteristics that contribute to beach erosion.

We present a protocol for using beach seines and simple surveys of benthic and coastal characteristics for long-term ecological studies of coastal fish communities. Based on the sampling effort needed to characterize and detect changes in communities, this paper describes a quantitative approach to characterization and comparison of temporally or spatially varying soft-bottom-associated fish communities.

Materials and methods

Location of study sites

Study sites were located along 16 km of the eastern shoreline of central Andros, a complex convoluted system of lengthy tidal creeks and lagoons (described in Love & Boardman 1990) . Like many islands, Andros has undergone shoreline alterations including construction of causeways and roadways, sand mining and the removal of coastal dune systems, and loss of native coastal vegetation, due in large part to invasion by the Australian pine, *Casuarina equisetifolia*, that dominates over 60% of the coastal zone of Andros (Hammerton 2001). Two sites, labeled Staniard Creek 1 and Staniard Creek 2, are less than 1 km apart along a contiguous stretch of beach in the settlement of Staniard Creek. Including two sites from the same stretch of beach allowed us to determine the sensitivity of fish community responses to subtle differences in coastal and benthic properties of two nearby, and presumably similar, locations.

Benthic and coastal characterization

We identified and classified coastal environments as per Sealey et al. (2002) using Land Sat 7 Thematic mapping and ground-truthing to determine coverage of the invasive *Casuarina equisetifolia*. We then ranked sites in order of increasing coverage of this species (the site with the lowest coverage was ranked 1, the site with the highest coverage was ranked 4). We evaluated the physical alterations of the dune system along the linear extent of the beach, and ranked the sites in order of increasing physical alterations.

Using a 60 m transect line perpendicular to shore, we completed point-intercept analysis (see Chiappone et al. 2001) with a 1m^2 quadrat to obtain mean cover estimates of bare sand, the seagrass *Thalassia testudinum*, and the macroalga *Batophora oerstedii*. These benthic surveys were completed seasonally in order to incorporate natural seasonal changes in benthic flora patterns.

Fish community characterization with beach seines

We used a seine net 20 m long and 1.5 m high, with a 1.2 m wide central pocket, with 1 cm mesh along the wings and 0.4 cm in the central pocket. Standard seining protocol was used to complete seines at different temporal stages. Time stages were defined as morning (earlier than 11:00 h EST), afternoon (between 11:00 and 16:00 h EST), and evening (after 16:00 h EST). Tidal stages were defined as high tide and low tide, with seine events occurring within an hour of the turning of the tide. Seasonal stages were defined as summer (July and August) or winter (January). Each 'seining event' consisted of four consecutive individual seines, done immediately after each other along adjacent stretches of coastline. The identity of each individual and the number of individuals per species were obtained by visual assessment and digital photographs of the catch on a gridded tray. Most fish were released unharmed, although specimens of unknown or questionable identity were preserved for later identification. When large schools of small silversides (Family Atherinidae) were collected, the abundance of these individuals was estimated.

Statistical analyses

Raw abundance data were fourth-root transformed to appropriately weigh the less abundant species and account for the high numbers of schooling fishes such as atherinids. Using the SPSS statistical package, a factorial ANOVA determined the effects of tidal stage, time of day, season, and site on the total numbers of individuals caught. Levene's test confirmed homogeneity of variances. Additionally, using PRIMER v5 ecological statistics software (Clarke & Warwick 2001), the total number of species, total number of individuals, and Shannon–Weiner diversity score were determined for each level of each temporal variable.

Mean data across sites were classified with hierarchical clustering using the Bray–Curtis group average linkage methods (Bray & Curtis 1957), then ordinated using non-metric multi-dimensional scaling (MDS plot). Significant differences in community composition were tested using PRIMER's multivariate equivalent of an analysis of variance (ANOVA), called 'analysis of similarities' (ANOSIM). All tests were based on 999 permutations, except for the season variable, where the maximum of 126 permutations was used. The key fish species responsible for the differences between sites were determined using the SIMPER routine, which calculates the average dissimilarity between each pair of samples, followed by computation of the average contribution of each species to the overall dissimilarity between samples (Clarke & Warwick 2001). The analyses were aimed at first characterizing the temporal changes in fish diversity and abundance, and then providing a qualitative summary of the differences between sites.

Results

Benthic surveys and sampling effort

Study sites varied considerably in a variety of benthic characteristics and coastal characteristics (see Table 1). Blanket Sound had the highest mean cover of both seagrass and algae and was the least disturbed in terms of exotic vegetation cover and physical disturbance to the coastline. Small Hope Bay had the highest degree of both physical coastal alterations and cover of the exotic Australian pine. The two locations at the Staniard Creek site were mostly similar in their benthic and coastal composition; the most obvious disparity between the two locations was the cover of the alga, *Batophora oerstedii* (Table 1).

We completed a total of 36 seine events, as shown in Table 2. A total of 1751 non-atherinid individuals (and an estimated 10 530 individuals including estimated atherinid counts) represented 36 species and 43 578g of fish biomass.

We generated a species-effort curve (Figure 1) by four random shuffles of the sequence of all 36 seine events. The power curve follows the equation $y = 6.9961x^{0.5094}$. Following the expected pattern, the proportion of species encountered increased as the number of seines increased, and leveled off at higher effort. Figure 1 indicates that 23 of the 36 species were observed at the completion of 10 seine events, while 32 species were observed at the completion of 20 seine events.

Temporal variability

We collected 15 species, including the flatfish *Trinectes inscriptus* and *Bothus ocellatus*, only at

Table 1. Summary of benthic and coastal characteristics of the study sites.

		Blanket Sound	Small Hope Bay	Staniard Creek	
				1	2
Benthic Characteristics	% Bare Sand	54.7	57.5	80.5	72. 7
	% Seagrass Cover (*Thalassia testudinum*)	25.8	19.9	13.4	14.4
	% macro-algae cover (*(Batophora oerstedii)*	12.8	11.1	1.6	10.4
Coastal Characteristics	Rank of Australian Pine (*Casuarina equisetifolia*) cover	1	4	2	3
	Rank of physical alterations	1	4	3	2

Benthic characteristics represent the averaged values from summer and winter surveys of the benthos. Coastal characteristics are ranked by the extent of each characteristic from lowest (1) to highest (4). Values for the Staniard Creek 2 site represent sampling from the summer only.

Table 2. Breakdown of the number of seine events completed at different tidal, time, and seasonal levels at each site.

Site	Tide		Time of Day			Season		Total
	High	Low	Morning	Afternoon	Evening	Summer	Winter	
Blanket Sound	5	4	3	4	2	5	4	9
Small Hope Bay	5	6	3	6	2	7	4	11
Staniard Creek 1	5	5	4	4	2	6	4	10
Staniard Creek 2	3	3	2	2	2	6	0	6

low tide, while we collected four species only at high tide (and also only once overall). We collected 10 species, including *Caranx bartholomaei*, and*Trinectes inscriptus* only during the summer and 11 species, including *Polydactylus oligodon* and *Harengula humeralis*, were unique to winter. Afternoon, evening, and morning samples produced 9, 1, and 4 unique species, respectively.

ANOVA (see Table 3) showed no significant difference in the total number of individuals caught at different times of day or at different tidal states, which typically varied in depth by less than 1 m. However, significantly more individuals were collected in the summer than in the winter. Table 3, which also provides diversity data, indicates that diversity was greater at high tide, but that number of individuals and species was greater at low tide (Table 3). Samples collected in the evening showed the highest diversity; samples collected in the morning were the least diverse. Shannon–Weiner diversity was higher in winter than in summer, although the number of species encountered was similar among seasons.

A two-dimensional MDS plot (Figure 2) revealed a clear division between summer and winter fish communities. ANOSIM confirmed a strong seasonal influence on fish communities (significance = 0.048%). ANOSIM also showed a significant effect of tidal state (significance = 0.02%), but not of time of day.

Site-to-site variability

Although the mean number of all individuals caught at Blanket Sound was an order of magnitude lower than at the other sites, total abundances did not vary significantly among sites (Table 3). Total abundances (of both all individuals and only non-atherinid individuals) did, however, display a positive relationship to the coverage of bare sand. Abundances were highest at Staniard Creek (80.5% bare sand) and lowest at Blanket Sound (54.7% bare sand). There were no other discernible relationships between the total number of all individuals or non-atherinid individuals and other benthic or coastal characteristics.

The fish community at Blanket Sound (the site characterized as the most ’intact’ in terms of anthropogenic influences and as having the highest cover of the seagrass *Thalassia testudinum* and the

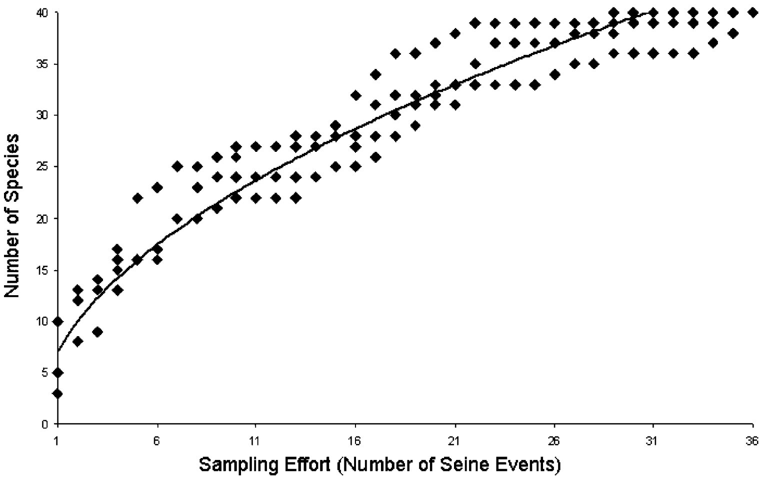

Figure 1. Species-sampling effort curve: A species–effort curve was generated by randomly shuffling the sequence of all seine events. The cumulative number of species encountered with each successive seine event was plotted for each of four random shuffles.

alga *Batophora oerstedii*) had the highest number of species and highest Shannon–Weiner diversity score. Furthermore, the fish community at Small Hope Bay (the site with the highest extent of *Casuarina equisetifolia* and physical alteration) had the lowest number of species and lowest diversity score. The diversity scores of fish communities from the Staniard Creek sites were also relatively low (Table 3), although the number of species observed at each site was markedly different, likely due to the lack of winter sampling at Staniard Creek 2.

A two-dimensional MDS plot (Figure 3) of the averaged values for each site–season combination depicts that fish communities were influenced primarily by site, even when strong seasonal variability was considered. ANOSIM indicated a significant difference (significance = 0.003%) in the fish communities at the different sites.

The SIMPER routing revealed that Blanket Sound was the least similar to the other sites. The lower abundance of atherinids at Blanket Sound was the strongest influence separating Blanket Sound from other sites, but the presence of *Sphoeroides testudineus*, *Trachinotus goodei*, and *Harengula humeralis* also contributed to distinguishing the Blanket Sound fish community from other sites. Fish communities at Blanket Sound and Staniard Creek were 58.44% dissimilar, while those of Blanket Sound and Small Hope Bay were 52.87% dissimilar. Small Hope Bay and Staniard Creek fish communities were, on average, only 35.81% dissimilar, with *Harengula humeralis*, *Eucinostomus lefroyi*, and *Albula vulpes* contributing most to their dissimilarity.

Discussion

Our results indicate that catches are highly variable from one seine event to the next. The results support the hypothesis that fish communities do vary temporally, and we determined that the temporal variability in fish communities varied mostly due to seasonal and tidal influences, and less so due to time of day. Although Shannon–Weiner diversity was the only variable that changed noticeably with time of day, these differences were very large and, therefore, should not be ignored.

The strongest temporal changes in fish communities were due to season. That total abundances were higher in summer than winter can best be explained by the fact that the large schools of atherinids were much more common during summer months. Furthermore, the overall community composition of species varied by season, suggesting that factors such as natural environmental (oceanographic) and climate changes, reproductive patterns, recruitment, and/or ontogenetic habitat shifts may influence the distribution of fishes in coastal waters. Regardless,

Table 3. Summary of univariate analyses for temporal and spatial effects.

		Temporal Effects							Spatial Effects			
		Tide		Time of day			Season		Site			
		High	Low	Morning	Afternoon	Evening	Summer	Winter	Blanket Sound	Small Hope Bay	Staniard Creek 1	Staniard Creek 2
Diversity indices	*S*	24	33	17	31	23	28	27	23	18	23	12
	N	4688 (843)	5842 (908)	1593 (729)	6659 (874)	2278 (148)	9309 (549)	1221 (1202)	251 (177)	3944 (410)	5576 (965)	759 (199)
	H'	0.84	0.76	0.35	0.67	1.56	0.33	1.7	2.12	0.5	0.78	0.9617
ANOVA	Mean	290.7	323.14	129.9	445.25	320.36	375	90.64	30	309.22	645.31	126.5
	Standard Error	16.43	16.6	20.12	17.68	24.43	13.97	20.33	23.72	21.08	22.19	27.39
	N	18	18	12	16	8	24	12	9	11	10	6
	p	0.074		0.737			0.010*		0.096			

Values for Staniard Creek 2 are based upon summer sampling only, since no winter sampling was done at that location. Diversity indices represent calculations of total number of species (S), total number of individuals (*N*), and Shannon–Weiner diversity value (*H'*). Two values are listed for each *N*; the first number represents total number of all individuals (with Atherinid counts estimated), and the second value in parentheses represents the total number of non-atherinid individuals. A factorial ANOVA on fourth-root transformed data tested the effects of temporal and spatial variables on total fish abundance, with significant factors marked by an asterisk. No significant interactions among variables were detected.

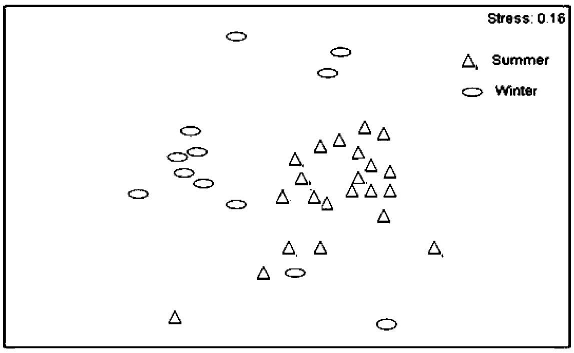

Figure 2. Two-dimensional MDS plot of all seine events. Each data point represents one seine event.

sampling must incorporate both seasons in order to maximize the accuracy of fish community characterizations.

Our results showed a significant tidal effect, which has also been documented in a variety of other studies, including those of coastal fish communities from North America (Layman 2000) and Asia (Suda et al. 2002). There are a few possible explanations for our findings of increased abundances and diversity of fish communities at high tide. First, high tide sampling naturally covers a greater volume of water, and, therefore, it is more likely that more fish will be present. Second, many of the fish collected from coastal waters were bottom-feeders that forage in sand for invertebrate prey, and thus, would more likely be collected at high tide seines, which covers larger expanses of bare sand characteristic of intertidal zones of beaches. Lastly, because seining at low tide was naturally focused on areas of higher cover of benthic vegetation than the sparsely vegetated intertidal zone that was sampled at high tide, there was a greater chance for fish to escape at low tide, when the lead line of the seine net could more easily be lifted-off the bottom as it passed over benthic flora. However, our sampling involved several people who snorkeled behind the seine net to hold the lead line down, thus reducing the possibility of fish escaping.

Overall, our data clearly suggest that adequate sampling must incorporate different tides, times, and seasons in order to most accurately characterize a site's fish community while controlling naturally-existing temporal variability. Such control is especially useful when one wishes to

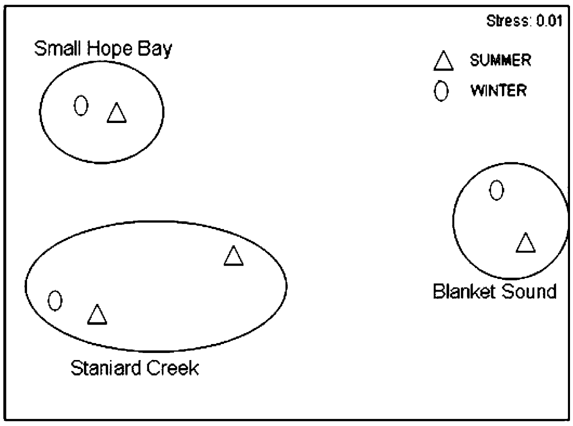

Figure 3. Two-dimensional MDS plot of site/season combinations. Each point represents the averaged values of species presence and abundances at a given site/season combination.

monitor long-term changes in the fish community at a site or to compare the fish communities at different sites. Thus, we suggest that the minimum acceptable sampling effort, as determined by a species-effort curve, be distributed evenly across different tides, times, and seasons.

Although the total number of fish did not vary significantly between sites, the fish communities at the different sites were distinct, as emphasized by the strong site-clustering in Figure 3. These results imply that site-specific characteristics do influence the structure of the fish community. We originally hypothesized that increased habitat structure (seagrass and benthic macro-algae coverage) would support a higher abundance and diversity of fishes. The data show that this hypothesis is partly true: Blanket Sound, with the highest coverage of both seagrass and macro-algae, did support the fish community with the highest diversity, but the opposite pattern was observed for fish abundances. The highest abundances of fishes were observed at sites with the lowest benthic complexity and highest cover of bare sand. Many fishes collected are invertebrate feeders (such as *Albula vulpes* and *Eucinostomus lefroyi*) that forage in the sand or planktivores (such as the atherinids), which may help to explain why more fishes were collected at less-vegetated sites. Fish abundance at Blanket Sound was lowest, most likely accounted for by the scarcity of schooling fishes such as atherinids and the clupeid *Harengula humeralis*.

Our second hypothesis, that coastal characteristics contributing to beach erosion would lead to a decrease in fish diversity and abundances, was also partly supported. The data showed an inverse relationship between erosion-causing activities and fish diversity, but again, no relationship between abundances and coastal characteristics was detected. Such findings indicate that coastal fish communities do respond to benthic and coastal characteristics, but that responses may more likely be evident in the *types* of fishes than in the *number* of fishes. Thus, attempts to correlate fish community composition to environmental features should focus on the presence and abundances of each species, and not simply total abundances.

Overall, Blanket Sound was the least similar to the other sites in terms of coastal and benthic features, and was also the least similar to the other sites in terms of its fish community. Staniard Creek and Small Hope Bay were more similar in their coastal features, and were similar in their fish communities as well. These results suggest that there is a relationship between physical benthic and coastal characteristics of a site and the fishes that use that site. Our data suggest that coastal characteristics may be more important than benthic flora characteristics in influencing fish community composition. However, because the number of benthic and coastal characteristics included was relatively large when compared to the number of sample sites, our data do not allow us to tease apart specifically which coastal and benthic factors are most responsible for observed differences. The data do indicate, however, that habitat characteristics do influence fish community composition. Future studies that include a larger number of sample sites could elucidate which specific features of coastal habitats are most influential in determining fish community composition.

It is important to mention that the two sampling sites at the Staniard Creek location, although less than 1 km apart, were not always the most similar in their fish communities. The noticeable difference in *Batophora oerstedii* coverage at the two Staniard Creek sites may be responsible for any noticeable differences in their fish communities. The coverage of *Batophora oerstedii* at Staniard Creek 2 more closely resembled that of Small Hope Bay than that of Staniard Creek 1. It may not be too surprising, then, that some aspects of the Staniard Creek 2 fish community, such as abundances and number of species observed, were closer to Small Hope Bay values than to Staniard Creek 1. Such results suggest that fish communities are highly sensitive and responsive to even seemingly subtle physical changes in coastal environments. Furthermore, our results imply that data from a relatively small sampling location cannot be used to infer details about the fish community along a larger stretch of coastline, since even minor environmental changes may significantly influence the distributions and abundances of fish species.

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