Fish Community and Habitat Assessments of Three Adjacent Tidal Creeks on Cape Eleuthera, The Bahamas

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Abstract.—Three adjacent tidal creek systems (Page, Kemps, and Broad creeks) on Cape Eleuthera, The Bahamas were studied to quantify the variation in fish community structure and habitat characteristics over small (<5 km) spatial scales. Snorkeling transects were used to census the fish community on a summer new moon during slack high tide and involved the simultaneous assessment of each creek and each zone within the creek (i.e., mouth, middle, and upper) replicated over three consecutive days. The simultaneous assessment (involving large teams) was done to enable direct comparison without spatial sampling being confounded by time. Habitat assessments included measurements of water quality parameters, sediment sampling, and vegetation surveys. Despite their close proximity, creeks differed in both fish community structure and habitat characteristics. Broad Creek had the greatest fish species richness (n = 15), followed by Kemps Creek (n = 14) and Page Creek (n = 10). Mangrove habitats had significantly greater fish species diversity in Broad Creek while sea grass habitats resulted in higher species richness in Page Creek, relative to other habitat types. Mangrove and algal plain habitats had the highest fish species diversity in Kemps Creek. Within creeks, fish abundance was dependent on zonation, with the largest number of fish being found in creek mouths compared to upper sections. Water quality parameters (i.e., temperature, dissolved oxygen, and salinity) differed among the creeks, presumably reflecting creek morphology. Out of the 10 different species of vegetation observed, 60% were found in all tidal creeks. Coarse sand was the predominant particle size for all creeks, with

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variation in the second most abundant particle size between Page Creek and the others. This study reveals the great heterogeneity of tidal creek fish community and habitat characteristics and illustrates that conservation and management strategies along with monitoring programs must recognize the variation that can occur among and within coastal creeks over relatively small spatial scales.

Introduction

Coastal creek systems are an important nearshore seascape, comprised of functionally connected habitats, including sea grasses, algal plains, sand flats, soft-sediment beds, and mangroves (Krumme 2009; Boström et al. 2011). Traditionally, habitats comprising this seascape have been studied as independent entities within the context of a larger coastal ecosystem. For example, mangroves (Blaber 2007) and sea grass meadows (Heck et al. 2003) have received much attention from scientists on an individual basis because of their high productivity, ability to stabilize sediment, and provision of key habitats for fish and invertebrate taxa. Mangroves in particular function as nursery, foraging, and refuge areas for fish in subtropical and tropical regions (Mumby et al. 2004; Lugendo et al. 2006; Nagelkerken et al. 2008; Walters et al. 2008). Due to the regular submersion and exposure of mangrove habitats associated with tidal cycles in most subtropical and tropical areas, however, few fish can exclusively inhabit these patches. Rather, some fish must migrate in and out, using alternative habitats such as sea grass beds when mangroves are unavailable (Sheaves 2005). Thus, the habitats comprising the coastal creek system mosaic are inherently connected not only through the physiochemical processes associated with tides, but also through the biota that move between the patches (Moberg and Folke 1999; Mumby 2006; Hitt et al. 2011).

At present, one of the most pressing needs of resource managers and decision makers is a better understanding of ecological connectivity in subtropical and tropical coastal systems (Grober-Dunsmore et al. 2009). Given the myriad of anthropogenic modifications that have occurred in these areas (reviewed in Gladstone 2009), a global push for conservation and management of subtropical and tropical coastal systems is crucial to reduce, reverse, and prevent unnatural changes and to maintain the ecological goods and services that they provide (UNEP 2006). While creating marine protected areas is one management strategy, it has been highlighted that current assessment practices of nursery habitats, for example, often take a static approach of considering coastal creek systems as individual and homogeneous entities (Nagelkerken et al. 2015). Instead, such seascapes are dynamic and spatially heterogeneous, with some configurations resulting in increased connectivity (Grober-Dunsmore et al. 2009) and higher densities of fish communities (MacDonald and Weis 2013).

To date, research efforts on coastal tidal creek systems tend to be focused on a single system or across multiple systems covering a broad geographic range. There are relatively few studies that examine the variation in fish assemblages and habitat in adjacent creeks on small (<5 km) spatial scales. Additionally, many studies at the fish community level (e.g., Layman et al. 2004; Mwandya et al. 2010) are conducted sequentially at different sites, which makes it difficult to control for temporal variability, even across several days where tides, photoperiod, lunar phase, and weather can vary substantially. As such, the purpose of this study was to simultaneously survey the fish community of three tidal creeks along a less than 5-km stretch of coastline on Cape Eleuthera, The Bahamas, replicated over a 3-d period, as well as collect data on the habitat characteristics in each creek.

Methods

Study location

This study took place on the island of Eleuthera, The Bahamas (N 24°50’05” and W 76°20’32”), in three coastal tidal creeks (Page Creek, Kemps Creek, and Broad Creek; see Murchie et al. 2013 for more details). Assessments of habitat and fish assemblages were facilitated by dividing each creek into three zones (mouth, middle, and upper; Figure 1). The mouth zone encompassed the opening of the creek and had the greatest depth at high tide (~1.2 m) and the highest water flow. The upper zone included areas of the creek with the lowest water depth at high tide (~0.3 m), and had little to no water at

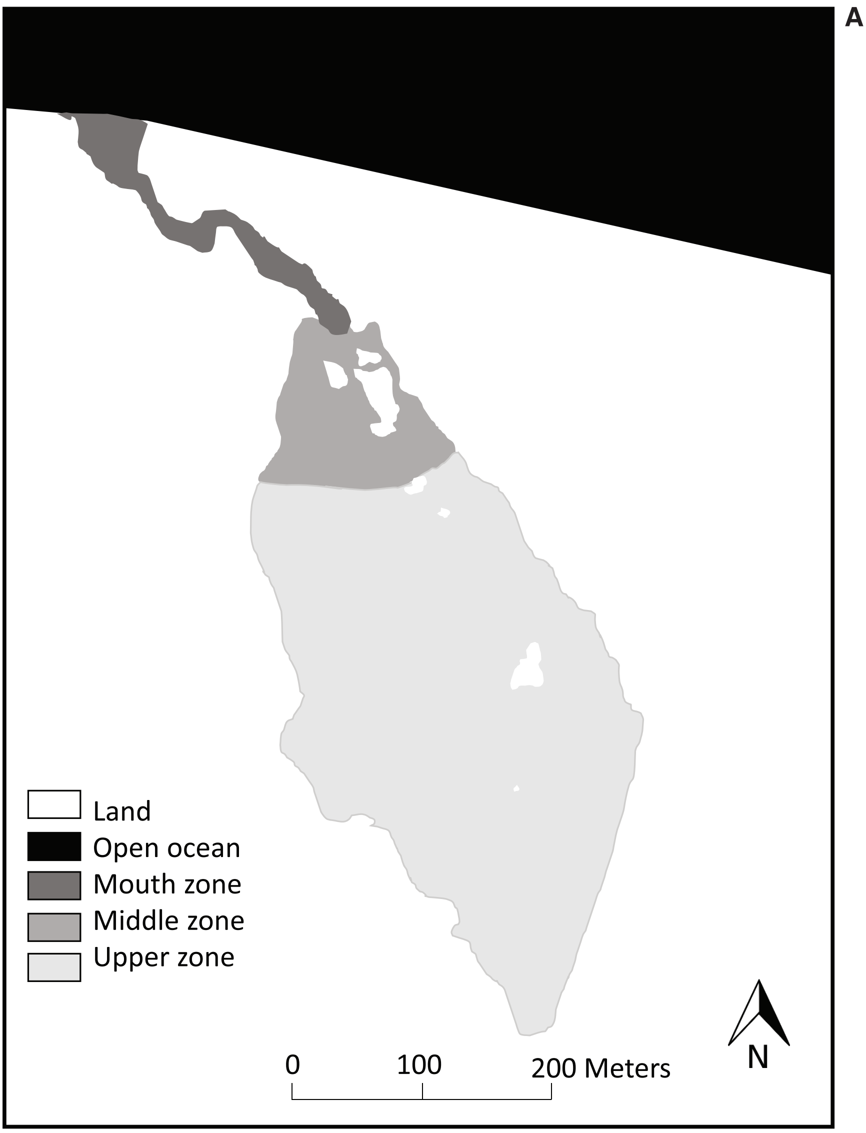
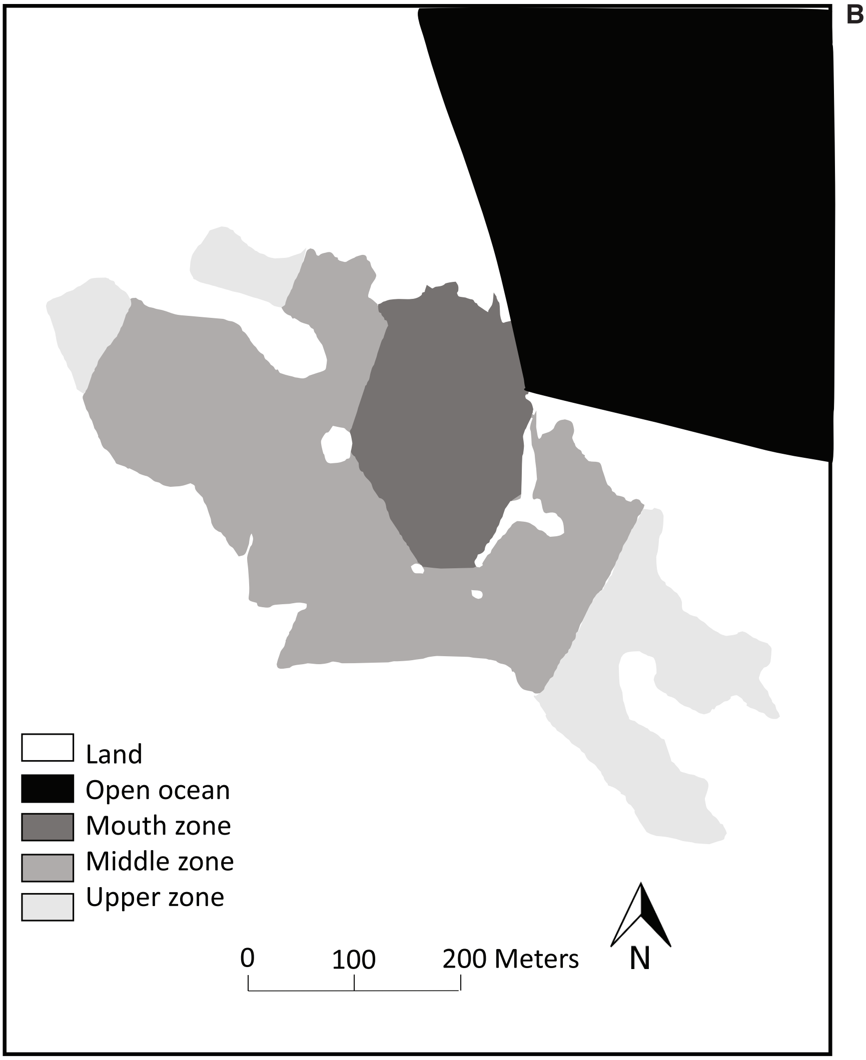


Figure 1.—Habitat zone designations (mouth, middle, and upper) for (A) Page Creek, (B) Kemps Creek, and (C) Broad Creek.



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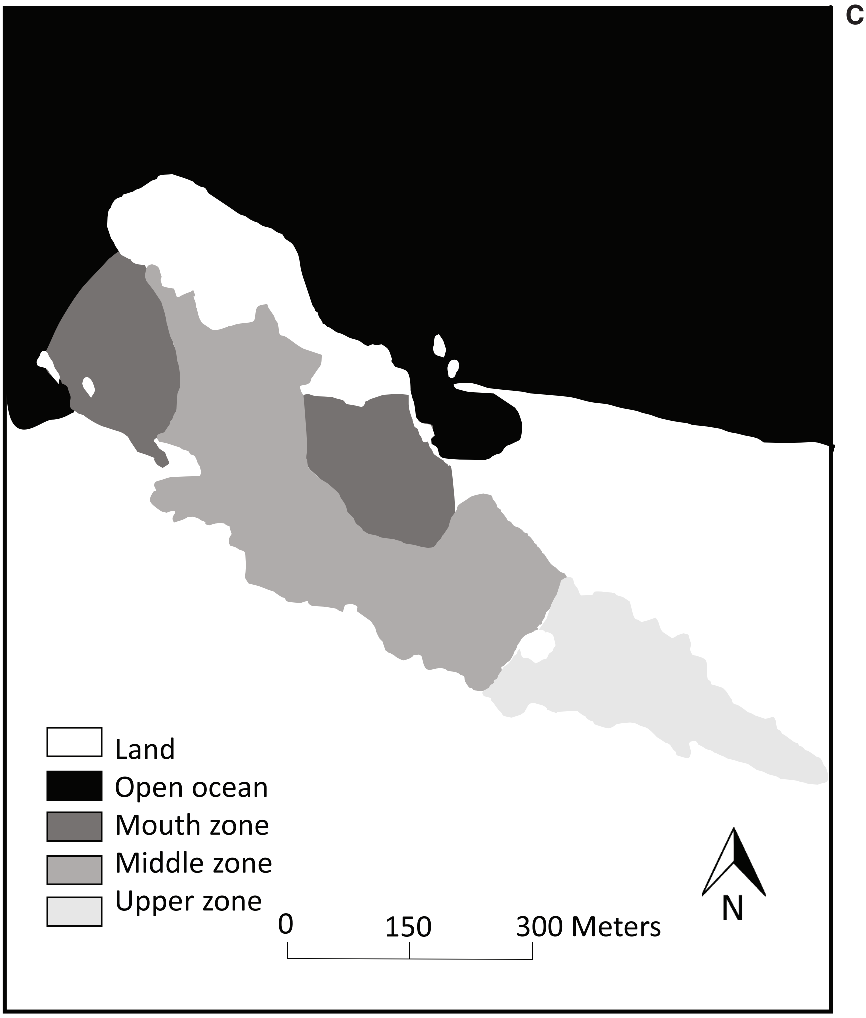
low tide. The middle zone encompassed all areas that were not designated as the mouth or upper zones. Sampling of the three creeks took place from August 22 to 24, 2006, during slack high tide. The lunar phase during this time was a new moon.

Fish community assessment

Underwater visual census was used to assess fish assemblages (Layman et al. 2004). Specifically, pairs of snorkelers swam in each zone of each creek simultaneously to provide a snapshot of the fish communities. Each snorkeling pair swam together in an s-shaped pattern at a rate of 3 m/min for a total of 5 min in each habitat type. All habitats in a specific zone were surveyed three times in a different location by the pair of swimmers. Data from each snorkeling pair was averaged to yield what was considered one sighting. Water depth was less than 2 m for all areas sampled, and visibility was at least 5 m. Species of *Eucinostomus* were lumped together due to the difficulty of accurately identifying Bigeye Mojarra *E. havana*, Flagfin Mojarra *E. melanopterus*, and Mottled Mo-



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jarra *E. lefroyi* under water. Other fish were identified to the lowest taxonomic level possible (e.g., damselfishes *Stegastes* spp., gobies *Gobidae* spp., needlefishes *Strongylura* spp., and silversides [atherinid species]). Species richness and relative abundance were determined for each creek and were summarized with a rank-abundance curve. A two-way analysis of variance (ANOVA) was used to test if there was a difference in the abundance of fish by zone within creek and among creeks. For each creek, an ANOVA was performed to examine if there was a temporal difference (over the 3 d of sampling) in fish abundance and diversity, as well as to assess if there were differences in fish abundance and diversity by habitat. Tukey-Kramer honest significance difference tests were performed following ANOVAs to determine where significant differences lie between variables (Day and Quinn 1989).

Habitat assessment

Water temperature, dissolved oxygen, and salinity were measured at increasing distances from the mouth of each creek using a YSI water quality meter (YSI 85, YSI Inc., Yellow Springs, Ohio, USA). An average of

12 readings were taken per creek up to a distance of 515 m from the mouth. Regression analyses were preformed to determine whether a relationship existed between the water-quality parameters and distance from the creek mouth. An ANOVA was used to determine whether there were differences in water temperature, salinity, and dissolved oxygen between the three coastal creeks.

Within each creek, habitat types were assessed. Habitat designations were based on Layman et al. (2004). Sand flats were defined by a rippled sandy bottom, as well as a lack of any type of dense vegetation. Algal flats had more than 50% algae cover while the sea grass habitat had greater than 50% sea grass cover. Soft sediment was defined as any area in which compaction of sediment was so low that experimenters sank. The mangrove habitat had similar characteristics to that of the soft sediment with the one major difference being the presence of mature red mangrove *Rhizophora mangle* or black mangrove *Avicennia germinans* trees. Within each zone (i.e., mouth, middle, and upper), vegetation sampling was accomplished by haphazardly throwing a bobbered weight and sampling the area where it landed. A 1 × 1 m quadrat was used to standardize the sampling area. Percentage of vegetation cover, along with a list of each species present, was recorded. A total of 10 quadrats were sampled in each zone of each creek.

A total of three sediment samples were collected per each habitat type found in each of the tidal creeks. Surface sediment samples were collected by filling a 200-mL cup to capacity. Following collection, samples were sieved through four mesh screens of decreasing size (#5, #10, #35, #120 U.S. standard sieve mesh size). The percentage composition by grain size (Wentworth 1922) was determined following sieving. A two-way ANOVA was conducted to determine if there was any difference in the overall percentage of sediment composition by creek and by habitat. As above, Tukey-Kramer honest significant difference tests were performed following all ANOVAs to determine where significant differences lie between variables. All statistical analyses on collected and derived data were completed using JMP 10 (SAS Institute, Cary, North Carolina). Maximal type-1 error rates were set at $\alpha = 0.05$.

Results

Fish community assessment

A total of 10,421 individual fish were documented during the 3-d simultaneous assessment of all three zones in Page, Kemps, and Broad creeks, with the greatest abundance of fish being recorded in Kemps Creek (n = 4,479; Table 1). Broad Creek had the next highest abundance of fish recorded (n = 4,022) followed by Page Creek (n = 1920). Rank-abundance curves for the three creeks showed that Broad Creek had the highest species richness (n = 15) followed by Kemps Creek and Page Creek with 14 and 10 species, respectively (Figure 2). Broad Creek had the most gradual slope of the rank-abundance curves, indicating a more equitable distribution of individuals among the species, which is a measure of species evenness. Out of the 15 species observed, 66% were documented in all three of the coastal creeks, with 47% of the species being documented in all three of the zones (i.e., mouth, middle, and upper; Table 1). All mojarra species (*Eucinostomus* spp. and Yellowfin Mojarra *Gerres cinereus*), as well as needlefish *Strongylura* spp. and silversides (atherinid species) were found in each of the five habitat types (Table 1).

A two-way ANOVA revealed no difference in the abundance of fish by creek (F = 1.93, df = 2, P = 0.15), but there was a significant difference in the abundance of fish by zone (F = 6.17, df = 2, P = 0.002). In particular, the mouth of the creeks contained a significantly larger number of fish, on average, than the upper portions of the creeks. No temporal variation in fish abundance or fish diversity was detected for any of the tidal creeks (all P-

Table 1.—Summary of the total number of each fish species observed

		Number of fish observed in each creek				
Common name	Scientific name	Page Creek (*n* = 1,920)	Kemps Creek (*n* = 4,479)	Broad Creek (*n* = 4,022)	Zone[a]	Habitat[b]
Great Barracuda	*Sphyraena barracuda*	15	24	7	1, 2	A, M, F, G
Bluehead	*Thalassoma bifasciatum*	0	0	2	1	G
Checkered Puffer	*Sphoeroides testudineus*	4	12	7	1, 2, 3	A, M, F, G
Damselfishes	*Stegastes* spp.	3	7	12	1, 2	A, M, G
French Grunt	*Haemulon flavolineatum*	828	441	1,054	1, 2	A, M, G
Gobies	Gobiidae	3	13	1	1, 2, 3	A, M, G
Lemon Shark	*Negaprion brevirostris*	2	6	2	1, 2, 3	A, M, G
Mojarras	*Eucinostomus* spp.	2	1	1	1, 2, 3	A, M, F, G, S
Needlefishes	*Stronglylura* spp.	288	201	193	1, 2, 3	A, M, F, G, S
Schoolmaster	*Lutjanus apodus*	337	95	70	1, 2, 3	A, M, F, G
Sergeant Major	*Abudefduf saxatilis*	0	2	4	1, 2	M
Silversides	atherinid species	0	3,433	1,930	1, 2	A, M, F, G, S
Slippery Dick	*Halichoeres bivittatus*	0	13	0	1	A, M, G
Southern Stingray	*Dasyatis americana*	0	0	3	1, 3	A, M
White Mullet	*Mugil curema*	0	58	682	1, 2, 3	A, F, G
Yellowfin Mojarra	*Gerres cinereus*	438	173	54	1, 2, 3	A, M, F, G, S

[a] Zones in which species were observed: 1 = mouth, 2 = middle, and 3 = upper.
[b] Habitats in which species were observed: A = algal plain, M = mangrove, F = sand flat, G = sea grass, and S = soft sediment.

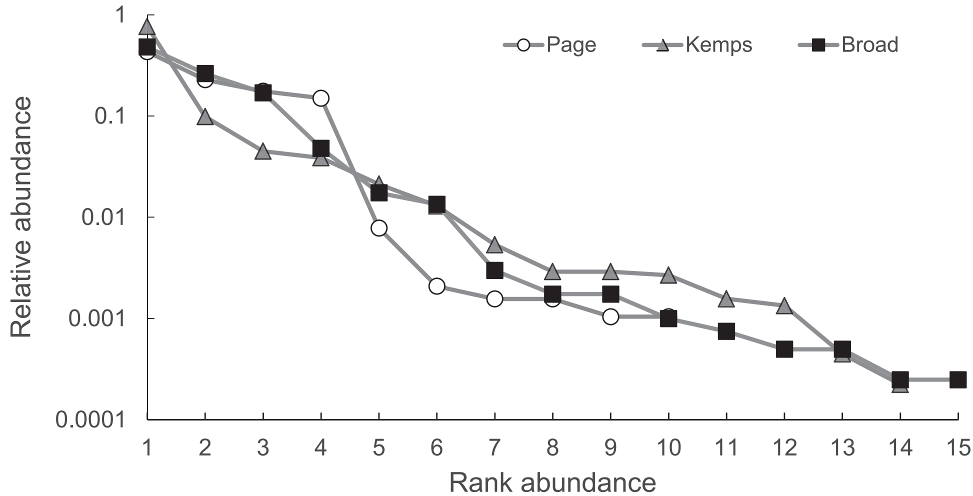

Figure 2.—Rank-abundance curves for the fish communities of Page, Kemps, and Broad creeks.

values > 0.10). There was also no significant difference in the abundance of fish by habitat type for each creek (all P-values > 0.20). There was, however, a difference in fish diversity by habitat type for each creek (Page Creek F = 4.61, df = 3, P = 0.005; Kemps Creek F = 8.41, df = 4, P < 0.0001; Broad Creek F = 5.15, df = 3, P = 0.003). Specifically, sea grass habitats had the greatest diversity of fish in Page Creek compared to all other habitat types, whereas mangrove habitats had the greatest diversity of fish in both Broad and Kemps creeks (although algal plain was not significantly different than mangrove habitats in Kemps Creek).

Habitat assessment

Water temperature increased significantly with increasing distance from the mouth zone in Page Creek (r^2 = 0.72, P < 0.001), but there was no significant relationship between water temperature and distance from the mouth for Kemps Creek (r^2 = 0.08, P = 0.49) and Broad Creek (r^2 = 0.04, P = 0.50). Results for salinity varied, with salinity increasing with distance from the mouth zone in Page Creek (r^2 = 0.42, P = 0.001), not changing in Kemps Creek (r^2 = 0.007, P = 0.85), and decreasing with distance from the mouth zone in Broad Creek (r^2 = 0.38, P = 0.015). Dissolved oxygen values increased with increasing distance from the mouth zone in Page and Broad creeks (r^2 = 0.69, P < 0.001 and r^2 = 0.50, P < 0.01, respectively) but did not change significantly in Kemps Creek (r^2 = 0.37, P = 0.107). Water temperature did not vary significantly between the creeks (F = 1.92, df = 2, P = 0.162; Table 3). Salinity was overall lower in Kemps Creek compared to the other two creeks (F = 12.26, df = 2, P < 0.001), and dissolved oxygen was significantly lower in Page Creek, relative to Kemps and Broad Creek (F = 13.94, df = 2, P < 0.0001; Table 2).

During vegetation surveys, a total of 10 species were documented, with five types of algae, three types of sea grass, and two species of mangrove (Table 3). A total of 60% of documented vegetation could be found in all three coastal creeks, with 40% being found in all three zones (*Dasycladus* spp., *Penicillus* spp., *Halodule beaudettei*, and red mangrove; Table 3). Only *Dasycladus* spp. and *H. beaudettei* could be found in all five habitats (Table 3).

For all three coastal creeks, coarse sand was the dominant sediment particle size (Figure 3). Fine sand was the second most abundant sediment particle in Kemps and Broad Creek, but granule was the second most abundant sediment particle in Page Creek. Indeed, Page Creek had a significantly

Table 2.—Mean water quality values (temperature, salinity, and DO) from Page Creek, Kemps Creek, and Broad Creek, in Eleuthera, The Bahamas. Dissimilar letters in each column indicate a significant difference between the creeks following a one-way analysis of variance.

Water quality parameters	Page Creek	Kemps Creek	Broad Creek
Mean temperature (°C)	29.7 z	29.4 z	29.6 z
Mean salinity (parts per thousand)	38.5 z	35.0 y	38.2 z
Mean DO (mg/L)	4.8 y	6.6 z	5.8 z

higher percentage of granule sediment particles than the other two creeks ($F = 5.90$, df = 2, $P = 0.007$), and Kemps and Broad creeks had significantly higher amounts of fine sand compared to Page Creek ($F = 9.71$, df = 2, $P = 0.0006$). The percentage of sediment type by habitat was significantly different for coarse sand ($F = 6.44$, df = 4, $P = 0.0007$) and fine sand ($F = 20.91$, df = 4, $P < 0.0001$). Fine sand was most abundant in mangrove habitats, whereas coarse sand was most comparably abundant in sand flat, sea grass, and algal plains relative to other habitat types.

Discussion

To our knowledge, this is the first study that has conducted simultaneous assessments of fish assemblages in multiple creek systems. While this methodology requires a large number of individuals who are trained to identify the various fish species, it allows the investigators to control for temporal variability where tides, photoperiod, and weather can vary substantially. Additionally, by conducting surveys in each zone of the creek simultaneously, the possibility of recounting the same individual fish is reduced but not eliminated. Although no differences in fish abundance or diversity were detected over the three consecutive day sampling period, longer temporal sampling would be expected to yield changes due to juvenile recruitment and seasonal migration patterns. Underwater visual census techniques such as those that have been employed in this

Table 3.—Summary of the various species of vegetation found during quadrat surveys of three coastal creeks in Eleuthera, The Bahamas.

Category	Scientific name	Creek[a]	Zone[b]	Habitat[c]
Algae	*Dasycladus* spp.	P, K, B	1, 2, 3	A, M, F, G, S
Algae	*Penicillus* spp.	K, B	1, 2, 3	A, F, G
Algae	*Halimeda* spp.	K, B	1, 2	F, G
Algae	*Udotea* spp.	B	2	A
Algae	*Acetabularia* spp.	P, K, B	1, 2	A, F, G
Sea grass	*Thalassia testudinum*	P, K, B	1, 2	A, F, G
Sea grass	*Halodule beaudettei*	P, K, B	1, 2, 3	A, M, F, G, S
Sea grass	*Syringodium filiforme*	P, B	1, 2	G
Mangrove	*Rhizophora mangle*	P, K, B	1, 2, 3	M, F
Mangrove	*Avicennia germinans*	P, K, B	2, 3	A, M

[a] Creeks in which species were observed: P = Page Creek, K = Kemps Creek, and B = Broad Creek.
[b] Zones in which species were observed: 1 = mouth, 2 = middle, and 3 = upper.
[c] Habitats in which species were observed: A = algal plain, M = mangrove, F = sand flat, G = sea grass, S = soft sediment.

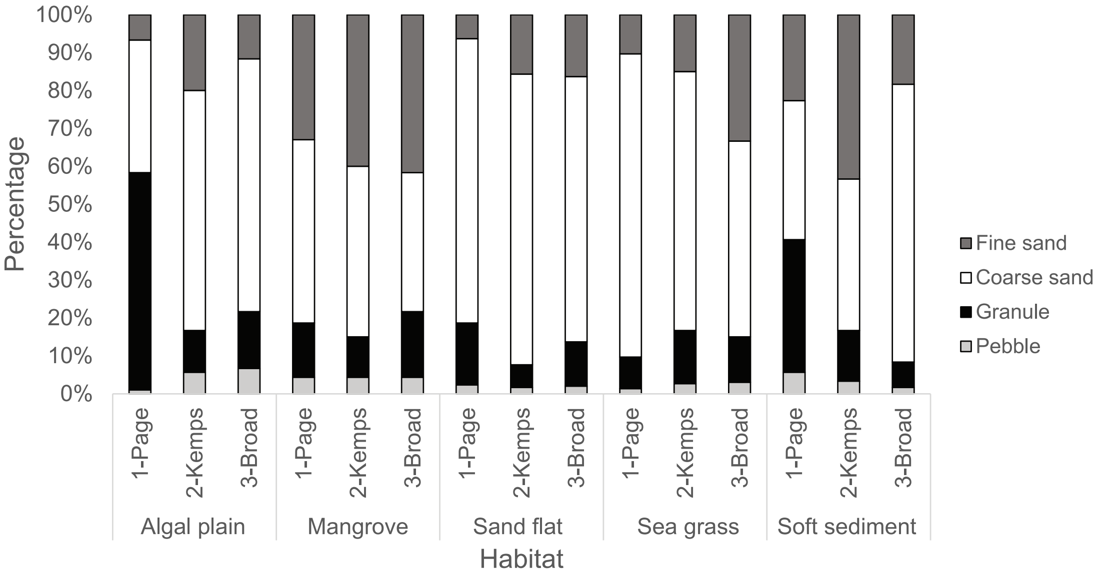

Figure 3.—Percentage of sediment particle size by habitat type for each of the three coastal creeks. The size ranges for the various classes of sediment particle size are as follows: pebble (4–8 mm), granule (2–4 mm), coarse sand (0.5–1 mm), and fine sand (125–250 μm).

study are appealing in the sense that they are nondestructive, but they have been criticized for underestimating fish density and diversity due to fish size (Willis 2001), fish behavior (Kulbicki 1998), and survey procedures (Ward-Paige et al. 2010). Indeed, our survey did not document the presence of Bonefish *Albula vulpes* in any of these tidal creeks, while telemetry studies by Murchie et al. (2013) demonstrate that adult Bonefish use all of these locations daily. It is likely that the activity associated with the large number of snorkelers in the creeks resulted in fish avoiding these areas (Murchie et al. 2009). However, Pita et al. (2014) found that use of human observers is more precise and complete compared to use of remotely operated vehicles or remote underwater video surveys.

It is likely that habitat characteristics and creek morphology are responsible for many of the findings in the fish community survey. For example, fish abundance was highest in creek mouths compared to upper reaches. This can be explained by the fact that habitat characteristics such as depth, water temperature, and salinity tend to make creek mouths more accessible to a wider diversity in size and species of fish (Tzeng and Wang 1992). Also, fish diversity among the creeks was overall highest in mangrove and sea grass habitats relative to soft sediment, sand flats, and algal plains. Mangrove habitats are known to offer many benefits to fish, including feeding grounds, predator refuges, and nursery habitats (Kathiresan and Bingham 2001). The heterogeneous environment of mangroves and their epibiotic diversity has a direct influence on fish community diversity (MacDonald and Weis 2013). Sea grasses are also known to offer many of the same benefits to fish as mangroves and are also considered important nursery habitats (Nagelkerken et al. 2001). One area that deserves attention in the future is the arrangement of the various habitats in these systems (i.e., habitat proximity and the amount of unsuitable low structure patches [e.g., sand flats]) to get a better grasp of ecological connectivity by using a landscape ecology approach (see Grober-Dunsmore et al. 2009; Nagelkerken et al. 2015).

Assessments of water quality parameters, vegetation, and sediment demonstrated the great heterogeneity of these tidal creeks, both within and among systems. While water temperature did not vary overall among the creeks, there were differences in water temperature profiles going from the mouth to the upper portions of each creek. Page Creek was the only location with a significant increase in water temperature with increasing distance from the mouth. This observation may be due to the fact that this creek is smaller in size compared to Kemps and Broad creeks and also because the mouth of Page Creek is narrower, deeper, and mangrove-lined, which blocks some of the direct sunlight. Salinity also increased with increasing distance from the mouth in Page Creek, likely due to evaporation of water from the upper portions of the creek (Sumner and Belaineh 2005). The lack of a salinity gradient from the mouth to upper reaches of Kemps Creek is possibly due to the fact that there are numerous deeper channels that run the length of the creek. The observed decrease in salinity with increasing distance from the mouth of Broad Creek is likely due to its morphology in that there are two mouths with direct exposure to open ocean. Dissolved oxygen increased with increasing distance from the mouths of Page and Broad creeks but did not change significantly in Kemps Creek. Further investigations are required to understand why Page and Broad creeks had increasing levels of dissolved oxygen towards the upper portions of the creek, given that mangrove habitats are typically lower in dissolved oxygen (Lewis and Gilmore 2007).

Vegetation differences that were detected among creeks may have been a result of the random sampling technique employed, and future studies within these systems should census the entire community. *Dasycladus* spp. and *Halodule beaudettei* were the only algae and sea grass, respectively, that were found in all five habitats in the creeks. *Halodule beaudettei* is known to be a pioneering species with an ability to establish productive stands in nutrient-poor sediments and waters (Smith 1996), which can explain its distribution throughout the creeks. The presence of macrophytes, such as sea grasses and macroalgae, is important in providing structure for fish habitat (Mwandya et al. 2010) and can also influence fish predation success (see Jaxion-Harm and Speight 2012).

All three coastal creeks studied were comprised of a heterogeneous mixture of sediment particle sizes, which is common for most coastal systems worldwide (Holland and Elmore 2008). Indeed, heterogeneity is significant in terms of its impact on coastal processes, such as wave friction, sediment transport, and bathymetric change (Holland and Elmore 2008). The bulk of the sediment material was coarse and fine sand, which is made exclusively by carbonate grains (Rankey and Reeder 2012). Mangrove and soft sediment habitats contained the highest concentration of fine sands, which can be attributed to their ease of travel in the water, allowing them to be deposited in middle to upper reaches in the creeks (Collinson and Thompson 1989). Page Creek had granule (2–4 mm) sediment as the second most abundant particle size, whereas both Kemps and Broad creeks had fine sand as the second most abundant particle size. The difference may be explained by the morphology of the creeks. Both Kemps and Broad creeks have much wider mouths (Broad Creek has two openings) when compared to Page Creek. The narrow mouth of Page Creek results in a channel, which concentrates wave energy and allows larger particles such as granules to travel further into the creek as they can only be carried in higher energy water (Collinson and Thompson 1989).

In conclusion, this study revealed the great heterogeneity of tidal creek fish communities and habitat characteristics and illustrated that conservation and management strategies, along with monitoring programs, must recognize the variation that can occur among and within coastal creeks over relatively small spatial scales. In particular, this has implications for site selection of marine protected areas as the heterogeneous nature of each creek and the specific arrangement of habitats will affect not only the diversity of the fish community present, but also its value for each species. While creek morphology clearly plays an important role in contributing to fish abundance and diversity, this is one of the most frequently altered components via anthropogenic disturbance. Managers need to consider all of these factors when confronted with conflicting objectives for conservation and alternative uses of tidal creeks when determining priorities.

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