ORIGINAL ARTICLE

Potential of Pigeon Creek, San Salvador, Bahamas, As Nursery Habitat for Juvenile Reef Fish

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ABSTRACT
This project assessed the significance of Pigeon Creek, San Salvador, Bahamas as a nursery habitat for coral reef fishes. Pigeon Creek's perimeter is lined with mangrove and limestone bedrock. The bottom is sand or sea grass and ranges in depth from exposed at low tide to a 3-m deep, tide-scoured channel. In June 2006 and January 2007, fish were counted and their maturity was recorded while sampling 112 of 309 possible 50-m transects along the perimeter of the Pigeon Creek. Excluding silversides (Atherinidae, 52% of fish counted), six families each comprised more than 1% of the total abundance (Scaridae/parrotfishes, 35.3%; Lutjanidae/snappers, 23.9%; Haemulidae/grunts, 21.0%; Gerreidae/mojarras, 8.5%; Pomacentridae/damselfishes, 6.1%; Labridae/wrasses, 2.4%). There were few differences in effort-adjusted counts among habitats (mangrove, bedrock, mixed), sections (north, middle, southwest) and seasons (summer 2006 and winter 2007). Red mangrove (*Rhizophora mangle*), covering 68% of the perimeter was where 62% of the fish were counted. Snappers, grunts and parrot fishes are important food fishes and significant families in terms of reef ecology around San Salvador. Mangrove was the most important habitat for snappers and grunts; bedrock was most important for parrot fishes. The southwest section was important for snappers, grunts and parrot fishes, the north section for grunts and parrot fishes, and the middle section for snappers. Among the non-silverside fish counted, 91.2% were juveniles. These results suggest that Pigeon Creek is an important nursery for the coral reefs surrounding San Salvador and should be protected from potential disturbances.

INTRODUCTION

About 100 families of bony fishes are associated with coral reefs but only four families, and one species of a fifth family lack a pelagic larval stage (Sale, 1991). Pelagic eggs and larvae have naturally high mortality during this critical period (reviewed by Ramirez-Mella & Garcia-Sais, 2003). Therefore, coral reef fishes are highly fecund (egg production ranges from 10,000 to one million per female; Sale, 1980). Because there is no parental care, offspring are at the

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mercy of planktivorous predators and density independent factors such as strong winds and currents.

Coastal habitats may intercept large numbers of pelagically-spawned larvae but recruitment of juvenile reef fish to coastal environments is highly variable (reviewed by Eggelston, Dahlgren, & Johnson, 2004). In temperate and tropical systems, juveniles often occur in shallow water then move to deeper water as they grow older (Sale, 1991), so high-quality habitats for juveniles are critical for future recruitment to adult stocks (Parrish, 1989).

A coastal lagoon is a transitional zone between land and sea, often an embayment separated from the coastal ocean by barrier islands (Herke & Rogers, 1999). A habitat is a nursery if its contribution per unit area of recruits to adult populations is greater, on average, than production from other habitats in which juveniles occur (Beck et al., 2001). Lagoons containing mangroves and sea-grass beds are ideal nurseries for the juveniles of coral reef species because of food abundance (high primary and secondary productivity), more shelter and less predation (Parrish, 1989; Laegdsgaard & Johnson, 2001; Nagelkerken et al., 2001; Eggleston et al., 2004; Krumhansl, McLaughlin, Sataloff, Grove, & Baldwin, 2007), as well as beneficial seascape features (Pittman, Caldow, Hile, & Monaco, 2007).

The Bahamian government is considering declaring selected areas around the island of San Salvador a National Marine Park, but work was needed to identify the most critical places for protection. Potential benefits of marine reserves are to (a) supply biomass of harvestable individuals via emigration to fished areas; (b) increase spawning-stock biomass, which may magnify recruitment; (c) restore natural size-frequency distributions of the protected populations, specifically to enhance larger size classes, which may affect sex ratios and reproductive output (Beck et al., 2001); (d) protect biodiversity; and (e) promote non-fishery economic benefits such as tourism. We evaluated the potential role of Pigeon Creek as a nursery reserve for coral reef fishes associated with San Salvador.

Our study (Conboy, 2007) had two foci: (a) to determine if Pigeon Creek is an important nursery habitat for juvenile coral reef fishes by counting fish in three habitats (mangrove, bedrock, and mixed) lining the perimeter of the three sections (north, middle, and southwest) of the Creek, and (b) to estimate standing stocks of species with more than 1% of non-Atherinidae (silversides) fish counts. Additional questions were: (c) Is mangrove more suitable than other habitats for juvenile fish in Pigeon Creek? (d) Are the numbers of fish observed inversely proportional to visibility while sampling? (c) Are fish counts higher at low tide when low water levels restrict them mostly to the mangrove root system?

Study area

Pigeon Creek is a shallow tidal lagoon at the southeastern end of San Salvador (Figure 1) with a variety of habitats potentially important for juvenile reef fishes, including sand flats, seagrass beds, mangrove prop roots, tidal channels and scattered hard substrates such as rock ledges, small reefs and harvested conch shell middens. It has two distinct areas: an extensive tidal to shallow subtidal flat surrounded by red mangrove (*Rhizophora mangle*) and a tidal channel near the entrance to the ocean (Welle et al., 2004); it is the major tidal mangrove habitat on the island (a much smaller area with adjacent seagrass habitat exists in Blackwood Bay of East French Bay (Gerace, Ostrander, & Smith, 1998).

Figure 1. *Map of Pigeon Creek and adjacent Snow Bay on San Salvador island with inset of the NE Caribbean region. Adapted from (Krumhansl et al., 2007) Reprinted with permission.*

Pigeon Creek was expected to be an important nursery habitat for juvenile grouper, snapper and other reef fishes because juvenile fish populations appeared to be higher in Pigeon Creek than at other areas around San Salvador (Krumhansl et al., 2007). Also, the fishes in Pigeon Creek are similar to those found in Fresh Creek (a confirmed nursery habitat) on Andros Island, Bahamas which also has habitats composed of seagrass, mangrove and bedrock (Layman & Silliman, 2002).

METHOD

Initial quick, wide-ranging qualitative surveys were done within ±3 hr of peak low tide by canoe and snorkeling in June 2006. It was assumed that during low tide fish would be forced to move from very shallow or exposed seagrass beds and sand flats to the deepest water available along the perimeter of Pigeon Creek, and that this would permit accurate population estimates with reasonable sampling effort. GPS waypoints (N=330) were recorded every 50 m along the 9.9 km perimeter of the tidal lagoon where water was present within ±3 hr of low tide.

Pigeon Creek has three distinct sections separated by narrow channels: north (31.2% of waypoints sampled), middle (30.6%) and southwest (38.2%), and three distinct habitats at a 50-m scale: mangrove (68.5% of waypoints sampled), bedrock (15.1%) and mixed (mangrove and bedrock, 16.4%). After the initial surveys, a stratified random sample of waypoints was sampled quantitatively, with greatest sampling effort in the southwest section and in mangrove habitat in both June 2006 and January 2007. We did not include seagrass beds or sand flats in the experimental design because during qualitative surveys very few fish, juveniles or adults, occupied these habitats compared to the mangrove and bedrock habitats.

To sample, a 50-m transect line was deployed by canoe parallel to and far enough away from the sample site so as not to disturb the fish. Once the transect line was in place, two snorkelers positioned themselves at the ends of the transect line (0 m and 50 m). Ten to 20 min (empirically determined during qualitative surveys, but usually 12 min) was spent identifying and counting (or estimating in the case of large schools, e.g., silversides) fish every 10 m along the transect line (0, 10, 20, 30, 40 and 50-m marks). A 2-m PVC pipe laid parallel to the transect line was used to define the field of observation at each 10-m mark. Counts were adjusted for count per unit effort (CPUE = [number of fish in each taxon observed per 50-m transect]/[total minutes of observation time per 50-m transect]*60 min = estimated count per hour) and log-transformed (log [CPUE + 1]) for statistical analysis. Separate timed, drift surveys using SCUBA were conducted near the mouth of Pigeon Creek where juvenile Nassau grouper had been reported (Krumhansl et al., 2007).

Fish lengths were estimated visually in the water. Each fish observed was placed in a reproductive class in one of two ways. Nassau grouper more than 25 cm total length (TL) were considered early or mature adults while Nassau grouper less than 25 cm were considered juveniles (Krumhansl et al., 2007). Gray snapper more than 25 cm also were considered adults, based on the relationship between their common maximum (45 cm) and maturity lengths (40-50% of maximum length; Carpenter, 2002). Other taxa were characterized as juvenile or adult by distinct colors or markings (Humann & DeLoach, 1996).

Three environmental parameters were recorded while conducting species counts. The period of tide (tide quarter: $\pm$3 hr peak low tide, next 6 hr, $\pm$3 hr peak high tide, next 6 hr), according to tide charts, was recorded for each transect sampled. Cloud cover (less than 33%, 33-66%, > 66%) and visibility, or distance seen when conducting population counts (< 3 m, 3-6 m, > 6 m), were estimated visually at each transect sampled. No environmental parameters were recorded during grouper surveys.

Sampling data were used to estimate juvenile reef fish standing stock by habitat and section of Pigeon Creek, and to assess the potential magnitude of Pigeon Creek as reef fish nursery habitat. The standing stock of each taxon greater than 1% of the non-silverside fish count was estimated for each habitat (mangrove, bedrock, mixed) and section (north, middle, southwest) by the following procedure: CPUE per 50-m sampling transect in each habitat and section was divided by five (to reflect actual fish counts during the mostly 12-min sampling times per 50-m transect; 60 min/12 min = 5) and multiplied by 50/12 (to reflect that fish were only counted at six, 2 m-wide locations along each 50-m transect). After estimating the average number of each taxon per transect in a habitat or section of Pigeon Creek (e.g., schoolmaster in mangrove habitat, gray snapper in the middle section), the averages were multiplied by the number of 50-m sampling sites in each category to estimate the standing stock of each taxon in that category. Values for the three habitats and three sections were summed separately for two estimates of total standing stocks for Pigeon Creek.

In a similar study, Eggelston et al. (2004) compared the mean density of reef fishes in seagrass, mangrove, channel, and patch reef habitats with t-tests. They did not use ANOVA because it would include habitat as a factor and they were unsure of the accuracy of their habitat classifications. By precisely defining the habitat of each sampled transect, we avoided this problem. General Linear Models (GLM) with cloud cover, visibility and period of tidal cycle as covariates were used to test hypotheses of differences in fish CPUE re: habitat (mangrove, bedrock, mixed), section of Pigeon Creek (north, middle, southwest) and season (June, January). Tukey's HSD tests distinguished among means with an experiment-wise error rate. One-way ANOVA was used to distinguish means when a GLM indicated that a covariate was significant.

RESULTS AND DISCUSSION

Fish Counts.

During the two sampling seasons, 19 families, 23 species, and 19,297 fish were counted at 58 sites in June 2006 and 54 sites in January 2007 (Table 1); most sites (51) were sampled in both seasons. Silversides were 52% of the fish counted, and they are excluded from the analyses that follow because they are not found on San Salvador's patch reefs and, technically, are not reef fish. However, given their abundance, silversides are likely important prey, particularly for snappers and grunts, in Pigeon Creek.

Table 1
Fish counts (> 1% of non-silversides) by habitat, section, and season.

	HABITAT			SECTION			SEASON	
Species/Family	Mangrove	Bedrock	Mixed	North	Middle	Southwest	June	January
Wrasses	88	41	91	12	81	127	133	87
Mojarras	530	142	99	568	159	44	231	540
Damselfish	278	109	167	125	206	223	272	282
Parrotfish	1413	380	1415	401	543	2264	688	2520
Gray Snapper	325	42	69	142	224	70	237	199
Grunts	1432	181	293	942	426	538	715	1191
Schoolmaster	1333	152	233	334	625	759	896	822
Other Fish <1%	201	16	28	43	75	127	84	168

Among the seven non-silverside taxa with more than 1% total fish abundance (parrotfishes, Scaridae, 35.3%; grunts, Haemulidae, 21.0%; snappers, Lutjanidae: schoolmaster, *Lutjanus apodus*, 19.1% and gray, *L. griseus*, 4.8%; mojarras, Gerridae, 8.5%; damselfishes, Pomacentridae, 6.1%; wrasses, Labridae, 2.4%), four are potentially important food fishes for the people of San Salvador (snappers: schoolmaster and gray, grunts, parrot fishes). The predominant taxon in June 2006 (64% of the non-silverside count) was parrot fishes (43%; Figure 2).

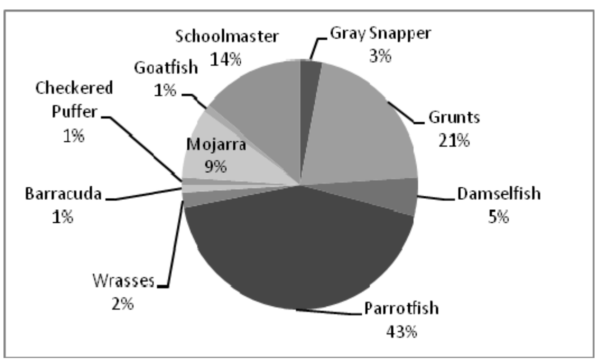

Figure 2. Percent abundance of each taxon > 1% of the total abundance of fish counted during June 2006.

In January 2007 (36% of the non-silverside count), the predominant taxa (Figure 3) were schoolmaster (28%), grunts (23%) and parrot fishes (22%). Based on reproductive status observed across both sampling seasons, 91.2% of the fish counted were juveniles.

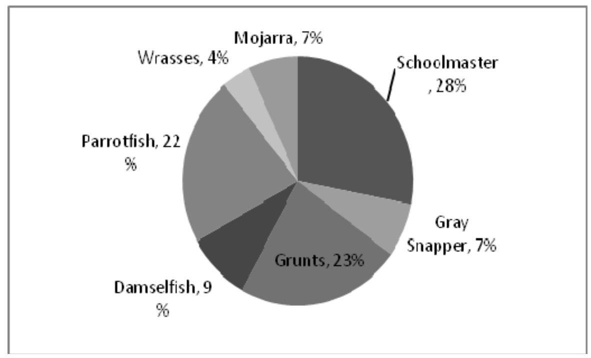

Figure 3. Percent abundance of each taxon > 1% of the total abundance of fish counted during January 2007

In a similar study looking at the importance of red mangrove to juvenile fishes in Pigeon Creek, Buchan (2005) observed nine non-silverside taxa with more than 1% of total abundance (parrot fishes, 29.2%; snappers, 27.8%; grunts, 18%; mojarras, 14.7%; damselfishes, 3.2%; barracuda, 1.5%; wrasses, 1.3%; puffers, 1.2%; goatfish, 1.1%), of which approximately 90% were juveniles.

Six of Buchan's nine taxa with more than 1% of the non-silverside count were among our seven taxa with more than 1%, and the eighth most common fish in our study was the checkered puffer at 0.7%. Krumhansl et al. (2007) also reported that mangrove roots and seagrass beds in Pigeon Creek are habitat for diverse juvenile reef fish species.

Adult parrot fishes, snappers and grunts are common on San Salvador's patch reefs, suggesting that recruitment from Pigeon

Creek is needed to maintain these taxa in the local reef fish communities.

Influences of habitat, section and season on fish counts (Tables 2-8).

There were no significant main effects (habitat, section, season) or interactions of main effects for parrot fishes (Table 2) and schoolmaster (Table 3).

Table 2.
*Count per unit effort of parrot fishes (*Scaridae*) in relation to habitat and section of Pigeon Creek, season and environmental conditions (tide quarter, cloud cover, visibility).*

Factors		*N*	Mean		p-value	Result	CV*
Habitat	Mangrove	79	110.66	66.45			7.7%
	Bedrock	13	213.22	166.67			13.3%
	Mixed	20	266.31	131.97	.127	Not significant	11.6%
Section	North	41	173.99	100.09			12.1%
	Middle	32	44.07	110.43			9.3%
	Southwest	39	372.12	97.77	.111	Not significant	7.9%
Season	June	58	292.64	78.87			7.6%
	January	54	100.81	81.89	.578	Not significant	7.2%
Interactions							
Habitat*Section					.207	Not significant	
Habitat*Season					.137	Not significant	
Section*Season					.254	Not significant	
Covariates							
Tide quarter					.483	Not significant	
Cloud cover					.361	Not significant	
Visibility					*.051*	*< 3 m, 3-6 m, > 6 m*	

*CV = coefficient of variation = Mean (log CPUE)/SEM (log CPUE)

Table 3.
*Count per unit effort of schoolmaster (*Lutjanus apodus*) in relation to habitat and section of Pigeon Creek, season and environmental conditions (tide quarter, cloud cover, visibility).*

Factors		*N*	Mean		p-value	Result	CV*
Habitat	Mangrove	79	92.45	13.06			3.7%
	Bedrock	13	73.34	32.75			8.9%
	Mixed	20	46.96	25.93	.961	Not significant	7.3%
Section	North	41	60.29	19.67			5.8%
	Middle	32	71.54	21.70			6.0%
	Southwest	39	80.92	19.21	.724	Not significant	5.1%
Season	June	58	49.70	15.50			4.4%
	January	54	92.14	16.09	.511	Not significant	4.4%
Interactions							
Habitat*Section					.822	Not significant	
Habitat*Season					*.058*	Not significant by Tukey's test	
Section*Season					.903	Not significant	
Covariates							
Tide quarter					.163	Not significant	
Cloud cover					.692	Not significant	
Visibility					.299	Not significant	

*CV = coefficient of variation = Mean (log CPUE)/SEM (log CPUE)

Habitats

Wrasses had significantly higher CPUE in bedrock than in mangrove (*p* = .022; Table 4) but they were also seen along the edge of the mangrove. Damselfishes had significantly higher CPUE in bedrock and mixed habitats than in mangrove (*p* = .017; Table 5). Due to their small sizes, damselfishes can utilize the spaces in pock-marked bedrock as protection from larger predators. The beaugregory (*Stegastes leucostictus*) and bicolor damselfish (*S. partitus*) are brightly colored, do not exhibit protective schooling (safety in numbers), and may require shelter in bedrock for protection. Also, damselfishes may be attracted to the bedrock and mixed habitats due to the food present; e.g., the beaugregory relies on ostracods in these habitats for food (Nagelkerken & van der Velde, 2004).

Sections

Wrasses (Table 4), damselfishes (Table 5), mojarras (Table 6) and gray snapper (Table 5) had significantly different CPUE among sections in Pigeon Creek. Wrasses (*p* = .005) and damsel-fishes (*p* = .017) were more abundant in the southwest and middle sections than in the north section. Mojarras were more abundant in the north section (wide expanses of sand flat) than in the middle and southwest sections (*p* = .010), while gray snapper were more abundant in the middle section than in the north and southwest sections (*p* = .031). Buchan (2005) also observed mojarras in greater abundance at sites with less benthic vegetation, such as the north section, where their silver color provides camouflage in open water over sand. Among sections, the southwest (36% of the Pigeon Creek's wetted perimeter within ±3 hr of low tide) had the highest fish CPUE (46%).

Seasons

Wrasses (Table 4) were more abundant in January than in June (*p* = .017), and mojarras (Table 6) were more abundant in June than in January (*p* = .049). Wrasses are year-round spawners (Brough, 2011), so it is not clear why counts were higher in January. Mojarras less than 5 cm long were abundant in the mangrove habitat in June, suggesting that winter/spring is the primary spawning period (Cyrus & Blaber, 1984).

Table 4

*Count per unit effort of wrasses (*Labridae*) in relation to habitat and section of Pigeon Creek, season and environmental conditions (tide quarter, cloud cover, visibility).*

Factors		*N*	Mean		p-value	Result	CV*
Habitat	Mangrove	79	6.48	1.77			13.7%
	Bedrock	13	24.15	4.44			14.8%
	Mixed	20	16.96	3.51	***.022***	***Bedrock>Mangrove***	18.2%
Section	North	41	3.31	2.67			**36.8%**
	Middle	32	20.72	2.94			11.8%
	Southwest	39	23.56	2.60	***.005***	***Southwest, Middle>North***	8.7%
Season	June	58	12.24	2.10			13.6
	January	54	19.49	2.18	***.017***	***January>June***	8.4%
Interactions							
Habitat*Section					***.015***	***Not interpretable***	
Habitat*Season					.402	Not significant	
Section*Season					.723	Not significant	
Covariates							
Tide quarter					*.067*	*TQ2, 4 > TQ 1, 3*	
Cloud cover					.334	Not significant	
Visibility					.140	Not significant	

*CV = coefficient of variation = Mean (log CPUE)/SEM (log CPUE)

Table 5

*Count per unit effort of damselfishes (*Pomacentridae*) in relation to habitat and section of Pigeon Creek, season and environmental conditions (tide quarter, cloud cover, visibility).*

Factors		N	Mean		p-value	Result	CV*
Habitat	Mangrove	79	20.84	2.76			8.2%
	Bedrock	13	41.38	6.93			12.7%
	Mixed	20	34.75	5.49	***.017***	***Bedrock, Mixed>Mangrove***	11.1%
Section	North	41	21.96	4.16			13.0%
	Middle	32	41.15	4.59			8.2%
	Southwest	39	33.87	4.06	***.017***	***Middle, Southwest>North***	8.1%
Season	June	58	33.58	3.28			7.2%
	January	54	31.08	3.40	.889	Not significant	7.3%
Interactions							
Habitat*Section					.384	Not significant	
Habitat*Season					.389	Not significant	
Section*Season					.482	Not significant	
Covariates							
Tide quarter					.342	Not significant	
Cloud cover					***.010***	***> 66%, 33-66% >< 33%***	
Visibility					.115	Not significant	

*CV = coefficient of variation = Mean (log CPUE)/SEM (log CPUE)

Juvenile parrot fishes and grunts exceeded 20% of the fish counted in both June 2006 and January 2007, while schoolmaster exceeded 20% in January 2007. Parrot fishes spawn throughout the year with greatest activity during the summer months (Bester, n.d.), grunts spawn from late fall to early spring (SeaWorld Parks & Entertainment, n.d.), and schoolmasters spawn throughout the spring and summer (Lee County Professional Guides Association, 2008). Given the lengthy spawning seasons and relatively long juvenile lives of parrot fishes and grunts, it was not surprising to find them equally abundant in June and January. Given the spring/summer spawning season of schoolmasters, it was not surprising to find more juveniles in the winter. CPUE was not significantly different between June and January for most taxa. It appears that Pigeon Creek is a year-round nursery for most taxa and is especially important for juvenile schoolmaster during the winter.

Habitat, section, season interactions

Habitat-section interactions were significant but not interpretable for wrasses (Table 4, p = .015), mojarras (Table 6, p = .064, suggestion of significance), gray snapper (Table 7, p = .052, suggestion of significance), and grunts (Table 8, p = .002). There was a suggestion of significance for the habitat-season interaction of gray snapper (Table 7, p = .084; Bedrock/January greater than all other habitat/season combinations except Bedrock/June). The section-season interaction was significant for grunts (Table 8, p = .044; North/June > North/January). No other habitat-section-season interactions for taxa with more than 1% total fish counts were significant.

Statistical issues

Field count data like those above are notoriously variable. However, substantial sample sizes (112 out of 305 possible to sample 50-m transects along the wetted perimeter of Pigeon Creek at ±3 hr of low tide) and log (N + 1)-transformations of count data gave coefficients of variation (CV = *SEM/M*) of less than 20% in most cases (Tables 2-8), a reasonable value for count data. Given the variable numbers of observations by category (habitat: mangrove, bedrock, mixed; section: north, middle, southwest; season: June 2006, January 2007), it was not possible to calculate the statistical power of each comparison directly, but low CV is a reasonable qualitative approximation of good power (i.e., the probability of accepting a null hypothesis of no differences among treatment groups when it is false is low).

Table 6

*Count per unit effort of mojarras (*Gerridae*) in relation to habitat and section of Pigeon Creek, season and environmental conditions (tide quarter, cloud cover, visibility).*

Factors		*N*	Mean		p-value	Result	CV*
Habitat	Mangrove	79	37.87	6.56			8.3%
	Bedrock	13	36.96	16.47			18.9%
	Mixed	20	38.29	13.04	.922	Not significant	15.7%
Section	North	41	66.08	9.89			8.2%
	Middle	32	24.11	10.91			17.0%
	Southwest	39	22.92	9.66	***.010***	***North>Middle, Southwest***	15.0%
Season	June	58	55.71	7.79			7.9%
	January	54	19.70	8..09	***.049***	***June>January***	12.1%
Interactions							
Habitat*Section					*.064*	*Not interpretable*	
Habitat*Season					.531	Not significant	
Section*Season					.787	Not significant	
Covariates							
Tide quarter					.168	Not significant	
Cloud cover					.931	Not significant	
Visibility					.654	Not significant	

*CV = coefficient of variation = Mean (log CPUE)/SEM (log CPUE)

CVs were less than 20% for all treatment groups of five of the seven taxa with more than 1% of the non-silverside count in this study (Tables 2-8). For wrasses in the north section of Pigeon Creek, the mean count was low and SEM was high (both due to many zero counts), so CV was high (36.8%, Table 4). For gray snapper, four of the seven CV values ranged from 22.9-31.5% (Table 7). Small sample sizes in bedrock (*N* = 13) and mixed (*N* = 20) habitats probably accounted for their relatively high *SEMs* and *CVs* greater than 20%. For sections, mean counts were low and *SEMs* were high (both due to many zero counts) in the north and southwest, so *CVs* were high in those sections. High *CV* values are explained by the structure of the data; it is unlikely that differences among groups within categories were missed due to low statistical power.

One statistical misstep was made in this study—pseudo-replication (Hurlbert, 1984) across seasons (June 2006, January 2007). A stratified random sample (habitat, section) of transects was surveyed in June, but most of the same transects were surveyed again in January. A new stratified, random sample should have been collected in January. However, given the movements of fish observed while sampling and the 6-month gap between sampling periods, it is unlikely that many of the same fish were re-sampled; therefore, the sampling results for the two seasons are reasonably independent.

Table 7

*Count per unit effort of gray snapper (*Lutjanus griseus*) in relation to habitat and section of Pigeon Creek, season and environmental conditions (tide quarter, cloud cover, visibility).*

Factors		*N*	Mean		p-value	Result	CV*
Habitat	Mangrove	79	17.64	3.49			13.2%
	Bedrock	13	18.27	8.76			22.9%
	Mixed	20	23.04	6.93	.545	Not significant	31.5%
Section	North	41	7.10	5.26			29.5%
	Middle	32	46.74	5.80			12.3%
	Southwest	39	5.11	5.14	***.031***	***Middle>North, South***	23.6%
Season	June	58	7.27	4.14			18.2%
	January	54	33.03	4.30	.153	Not significant	12.3%
Interactions							
Habitat*Section					.052	Not interpretable	
Habitat*Season					*.054*	*Bedrock/January all but Bedrock/June*	
Section*Season					.190	Not significant	
Covariates							
Tide quarter					.918	Not significant	
Cloud cover					.550	Not significant	
Visibility					.327	< 3 m ,3-6 m, > 6 m	

*CV = coefficient of variation = Mean (log CPUE)/SEM (log CPUE)

Table 8

*Count per unit effort of grunts (*Haemulidae*) in relation to habitat and section of Pigeon Creek, season and environmental conditions (tide quarter, cloud cover, visibility).*

Factors		*N*	Mean		p-value	Result	CV*
Habitat	Mangrove	79	101.18	11.56			4.8%
	Bedrock	13	109.83	29.01			11.3%
	Mixed	20	72.90	22.97	.459	Not significant	11.0%
Section	North	41	121.02	17.42			7.0%
	Middle	32	62.34	19.22			8.8%
	Southwest	39	100.55	17.02	.685	Not significant	6.5%
Season	June	58	106.28	13.73			5.3%
	January	54	82.99	14.25	.107	Not significant	6.7%
Interactions							
Habitat*Section					***.002***	***Not interpretable***	
Habitat*Season					*.069*	*Not significant by Tukey's test*	
Section*Season					***.044***	***North/June>North/January***	
Covariates							
Tide quarter					.608	Not significant	
Cloud cover					.141	Not significant	
Visibility					.383	Not significant	

*CV = coefficient of variation = Mean (log CPUE)/SEM (log CPUE)

Influences of environmental conditions on fish CPUE

Water temperatures were measured on only a few days but were constant at waypoints visited on the same days. The average water temperature during June 2006 was 32.0 °C while during January 2007 it was 25.9 °C. It is unlikely that within-season temperature variations influenced fish CPUE. Environmental factors evaluated as covariates in relation to fish counts were tide quarter (TQ 1 = $\pm$3 hr of peak low tide, TQ 2 = next 6 hr, TQ 3 = $\pm$3 hr of peak high tide, TQ 4 = next 6 hr), percentage of cloud cover, and water visibility (m). No covariates were significant for mojarras (Table 4), gray snapper (Table 5), schoolmaster (Table 3), and grunts (Table 8).

<u>Tide quarter</u>

In both seasons most counts (60.7%) were made $\pm$3 hr around peak low tide. This served to concentrate fish in the deepest water along the perimeter of Pigeon Creek rather than have them spread across shallow seagrass beds and sand flats where they could not be counted easily. However, in the north section of Pigeon Creek during low tide some of the mangrove habitat was still submerged water of 2 m or greater depth, making it difficult to observe and count fish. For wrasses (Table 4), the results suggested that the effect of tide quarter was significant (p = .067); a separate one-way ANOVA indicated that CPUE was higher in tide quarters 2 and 4 than in tide quarters 1 and 3. This may have occurred because currents are greater in tide quarters 1 and 3 than in 2 and 4; therefore, wrasses may have been deeper in mangrove to avoid higher currents and harder to see. In sum, the hypothesis that CPUE would be higher near low tide was not supported by our data.

<u>Cloud cover</u>

In June 2006 cloud cover was less than 33% during 54.5% of sampling days but in January 2007 cloud cover was more than 66% during 43.6% of sampling days, expected results for summer (June) vs. winter (January) weather. For damselfishes CPUE (Table 5) was significantly higher (p = .010) when cloud cover was more than 34% than when it was less than 33%, suggesting that bright sunlight made them less likely to be within view of observers. Although it was anticipated that greater cloud cover would reduce visibility and CPUE, except for the reverse situation for damselfishes, there were no differences in CPUE related to cloud cover.

<u>Visibility</u>

Pluralities of observations were in the 0-3 m visibility range during June 2006 (43.6%) and January 2007 (43.1%). For parrot fishes (Table 2), the results suggested that visibility was a significant factor (p = .051); CPUE was higher when visibility was less than 3 m than when it was equal to or greater than 3 m. The hypothesis that decreased visibility (as indicated by greater cloud cover or more turbidity) would result in lower CPUE was not supported for the other taxa, so we have confidence in the comparability of fish counts across environmental conditions.

Nassau grouper

Nassau grouper were only 0.03% of the non-silverside fish counted (N = 6) during the 112 standard 50-m transect surveys conducted in both seasons. However, 36 were counted during four timed swims (33 min total) in January 2007; 32 were less than 25 cm and 4 were more than 25 cm. Based on Krumhansl et al.'s (2007) size-based definition of an adult, only 4 of the 36 Nassau grouper we counted were adults.

The Nassau grouper is an important Bahamian fish—socially, economically and ecologically (Sluka, Chiappone, Sullivan, & Wright, 1997; Krumhansl et al., 2007). In particular, it plays an important ecological role in near-shore habitats as a top predator, so the health of the Nassau grouper population is essential for maintaining the ecological health of the reef system. Healthy patch reefs are necessary to support San Salvador's artisanal Nassau grouper fishery, reef community structure, and tourism-dependent businesses.

Similar to observations by Krumhansl et al. (2007) at San Salvador and Layman and Silliman (2002) at Andros Island, Bahamas, the Nassau grouper in our study were observed at coral or conch shell middens, rocky overhangs or tide channels scoured through seagrass habitat. The main channel of the southwest section of Pigeon Creek may be considered a "waiting room" (Parrish, 1989) for juvenile Nassau grouper before they make their ontogenetic shift to San Salvador's reefs. Pigeon Creek, particularly the channel of the southwest section, likely supports the adult population of Nassau grouper at San Salvador (Eggleston, Grover, & Lipcius, 1998; Krumhansl et al., 2007). This area should be considered critical habitat and protected.

Estimated standing stocks of fish in Pigeon Creek

Standing stocks (95% CIs) of the seven taxa with more than 1% abundance in Pigeon Creek were estimated for habitats (mangrove, 25,519-86,854 fish; bedrock, 7,879-24,444; mixed, 4,019-9,848) and sections (southwest, 47,625-72,568; north, 10,533-60,049; middle, -2,335-38,148; Table 9). Low and high estimates of the total standing stock of common reef fishes in Pigeon Creek range from 37,417 to 121,146 using estimates by habitat and from 55,823 to 176,688 using estimates by section. Anywhere from 37,000 to 177,000 mostly juvenile reef fishes, excluding silversides, are estimated to live in Pigeon Creek.

Table 9
Standing stock estimates (95% CIs) of species > 1% total abundance in Pigeon Creek

Habitat	Mangrove			Bedrock			Mixed		
Species	Transects	Mean 2SE	Mean + 2SE	Transects	Mean 2SE	Mean + 2SE	Transects	Mean 2SE	Mean + 2SE
Wrasses	209	427	1,424	46	616	893	50	187	284
Mojarras	209	3,592	7,401	46	640	1,670	50	351	713
Damselfish	209	2,224	3,826	46	1,077	1,510	50	406	559
Parrotfish	209	-3,228	35,350	46	1,455	11,872	50	1,866	5,532
Gray Snapper	209	1,547	3,573	46	297	845	50	224	416
Grunts	209	11,330	18,041	46	2,526	4,339	50	693	1,332
Schoolmaster	209	9,627	17,209	46	1,268	3,315	50	292	1,012
Total		25,519	86,824		7,879	24,444		4,019	9,848

Estimated standing stocks (95% CIs) of the ecologically important food fishes—snappers: gray and schoolmaster, grunts (all predators) and parrot fishes (macroalgae grazers)—are 19,076-74,173 for the mangrove habitat, 5,546-20,371 for the bedrock habitat, 3,105-8,292 for the mixed habitat, 40,700-63,936 for the southwest section, 6,029-50,343 for the north section, and -5,165-31,067 for the middle section (data summed from Table 9). Low and high estimates of the total standing stock of ecologically important food fishes in Pigeon Creek range from 27,727-102,836 using estimates by habitat and from 41,564-145,346 using estimates by section. Anywhere from 27,000 to 145,000 mostly juvenile snappers, grunts and parrot fishes are estimated to live in Pigeon Creek. In sum, tens of thousands of juvenile reef fishes live in Pigeon Creek, especially in mangrove habitat and in the southwest section (Table 9).

Common to many field studies, we estimated standing stocks of fishes from extrapolations of 12 m of actual observations per 50-m transect to all of Pigeon Creek. Given extreme site-to-site variation in fish counts (including many zero counts) due to a variety of potential physical (e.g., currents, distance from the lagoon opening, habitat structure, distance to other habitats, etc.) and biological (e.g., degrees of fish site attachment re: movement, schooling, etc.) factors (see Buchan 2005), the potential for great extrapolation errors existed. However, because of the large sample sizes in our study (transects and fish counts) we believe our rapid assessment technique for estimating standing stocks was a reasonable approach.

DISCUSSION

Krumhansl et al. (2007) concluded after their study of a *mangrove lagoon-seagrass complex* in Pigeon Creek that Nassau grouper and Queen Conch (*Strombas gigas*) use it as nursery habitat, in particular the area closest to the mouth (lower middle section in our study). They also observed a mean of 5.5 juvenile Caribbean Spiny Lobster (*Panulirus argos*) per hectare.

For a tidal estuary on Andros Island, Bahamas, Layman and Silliman (2002) found that mangrove and seagrass habitats were dominated by grunts and snappers and had higher species diversity than sand flats. Consequently, they recommended preserving not only the mangrove habitat but also the adjacent seagrass beds. In addition, underwater video monitoring has confirmed nocturnal movements of gray snapper between mangrove and seagrass habitats (Luo, Serafy, Sponaugle, Teare, & Kieckbusch, 2009). While our study did not sample seagrass beds specifically (see Buchan, 2005), seagrass beds lay just offshore of many of the perimeter transects sampled, especially in the southwest section. The high abundance and diversity of juvenile reef fishes among the seagrass beds of Pigeon Creek reported by Buchan (2005), combined with our results for mangrove and bedrock habitats along the shore, suggest that Pigeon Creek has the characteristics of a productive nursery habitat for reef fishes.

Many other studies have documented the importance of estuaries and lagoons as reef fish nursery habitat in the Caribbean region (reviewed by Layman & Silliman, 2002), and it is generally accepted that mangrove is important nursery habitat for juveniles of many reef fishes and invertebrates that eventually recruit to nearby coral reef populations (Parrish, 1989; Nagelkerken et al., 2000; Beck et al., 2001; Layman & Silliman, 2002; Chittar, Fryer, & Sale, 2004). For example, Nagelkerken et al. (2001) compared bays with and without mangrove/seagrass habitats on a single island; juveniles of the 17 species studied were abundant in the mangrove/seagrass-dominated bays but largely absent in bays lacking these habitats. Additionally, Mateo et al. (2010) provided the first evidence of movements of French grunts and schoolmasters between mangroves and surrounding reef habitats using otolith chemistry.

Of the nine species studied by Cocheret de la Morinière, Pollux, Nagelkerken, and van der Velde (2002) in a bay and nearby fringing reef at Curacao in the Netherlands Antilles, grunts, parrot fishes and snappers (the most abundant taxa in our study), all had spatial distributions in which the smallest fish were found in the bay and the largest fish were found on the adjacent reef. These results suggest that juveniles settle and grow in habitats such as seagrass beds and mangroves, after which sub-adults move to reefs where they become sexually mature. The same spatial distribution of size classes occurs between Pigeon Creek and the patch reefs around San Salvador.

According to Buchan (2005), the mangrove prop root system in Pigeon Creek is used by juveniles because it provides the complex structure and shade necessary for protection from predators and sun while supplying food in the form of epiphytic algae and invertebrates (see also Gratwicke, Petrovic, & Speight, 2006). The abundance of juvenile parrot fish (macroalgae feeders) and snappers and grunts (invertebrate feeders) amongst the mangrove prop roots suggests that this habitat is of particular importance to these abundant families. For example, schoolmaster and gray snapper moved and rested in large schools in mangrove habitat (Buchan 2005, this study).

Cocheret de la Moriniere et al. (2002) showed that grunts exposed to artificial mangrove units were attracted to more structurally complex and shaded habitats. More evidence for the importance of mangrove prop root habitat for some reef fishes comes from a study by Nagelkerken and van der Velde (2004) at the Caribbean island of Curacao where the diet of the smallmouth grunt (*Haemulon chrysargyreum*) was primarily Tanaidacea (tiny crustaceans) that live in mangrove habitat but not seagrass beds. Biotic and abiotic compounds in the water of mangrove and seagrass habitats also may play a role in where post-larval fish are found during their juvenile life stage (e.g., French grunts; Huijbers, Mollee, & Nagelkerken, 2008). However, we observed few differences in reef fish CPUE among habitats. Mangrove comprised 68% of the fish habitat along the perimeter of Pigeon Creek, and the greatest number of fish was counted in mangrove (62%). Therefore, mangrove is important as nursery habitat in Pigeon Creek because of its great abundance, not because it holds more fish per unit of perimeter than other habitats.

Mangrove along the perimeter of the southwest section of Pigeon Creek is bordered by turtle (*Thalassia testudineum*) and manatee (*Syringodium filiforme*) seagrasses, whereas mangrove in the middle and north sections is more commonly bordered by sand. Which habitats and sections of Pigeon Creek are most important for the three major groups of ecologically important food fishes we sampled? For snappers, standing stock was much higher in mangrove and bedrock than in mixed habitat and higher in the middle and southwest sections than in the north section. For grunts, standing stock in mangrove and bedrock was much higher than in mixed habitat and higher in the southwest and north sections than in the middle section. For parrot fishes, standing stock over bedrock was much higher than in mangrove and mixed habitat and much higher in the southwest section than in the north section which was much higher than in the middle section. Therefore, mangrove and bedrock habitats are both important (mixed habitat is simply a combination of the two), and the importance of a habitat or section re species protection depends on the taxon of interest. Although these differing habitat, section and species combinations point toward the southwest section of Pigeon Creek as a focus for protection efforts, the fact that virtually nothing is known about potentially complex ecological interactions among the sections in the Pigeon Creek lagoon suggests that all of Pigeon Creek should be protected from development, dredging, etc., until there is a better understanding of the ecological dynamics of the lagoon system.

CONCLUSION

The major purpose of our study was to assess the importance of including all or parts of Pigeon Creek in the National Marine Park proposed for San Salvador, especially in light of potential new residential development along Pigeon Creek (Hartnell, 2007). Since our study in 2006-2007 there has been no plan for development or construction at Pigeon Creek; a resort development is occurring on the east coast of the island (T. Rothfus, personal communication, March 2011). Given the large area of Pigeon Creek (and little similar habitat elsewhere on San Salvador; Gerace et al., 1998) relative to the small littoral shelf surrounding the island, Pigeon Creek is likely the major source of recruitment to San Salvador's reef fish community. Patch reef fishes are important to the artisanal fishery and for tourism at San Salvador. Damage to the Pigeon Creek ecosystem and its biological productivity likely will adversely affect patch reef ecology and the local economy. The entire Pigeon Creek ecosystem is linked physically but we do not know enough about it yet to say that some parts can be changed without adversely affecting the ecological functioning of other parts that we know are important now. For San Salvador's economic and ecological health, it would be wise to protect all of Pigeon Creek immediately.

Based on the results of this and similar studies, we specifically recommend:

1. No dredging to allow increased boat traffic should be permitted, as this could alter sediment dynamics and potentially smother important seagrass habitat.

2. Fishing in the lagoon should be limited to avoid diminishing recruitment to nearby patch reefs.

3. Inappropriate use of watercraft should be controlled to prevent erosion and sedimentation of seagrass beds.

4. Sewage from any development should be treated to high standards.

5. Because the area around Pigeon Creek also provides important habitat for birds, land clearing should be minimized.

6. The main channel of the southwest section, the mouth of Pigeon Creek, and Snow Bay (Krumhansl et al., 2007) should be considered a "waiting room" (Parrish, 1989) for juvenile Nassau grouper, Queen Conch and Caribbean Spiny Lobster before they make ontogenetic shifts to San Salvador's patch reefs. These are critical habitats and must be protected to ensure recruitment.

7. Studies like ours and those of Buchan (2005) and Krumhansl et al. (2007) should be repeated at regular intervals to monitor the ecological health of the key habitats and sections in Pigeon Creek and to conduct population surveys to establish any changes in abundance of the important juvenile fishes (Nassau grouper, snappers, parrot fishes, grunts) and invertebrates (Queen Conch and Caribbean Spiny Lobster).

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