

Video Estimates of Red Snapper and Associated Fish Assemblages on Sand, Shell, and Natural Reef Habitats in the North-Central Gulf of Mexico

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Abstract.—Video estimation of the relative abundance of fishes is a noninvasive method commonly used to assess fish densities. This technique can be used to characterize habitat use patterns either of fish assemblages or of a particular species of interest. The objectives of this study were to quantify relative abundance of red snapper, *Lutjanus campechanus*, and to characterize with video methodology the associated fish assemblages over different habitat types. Fishes were enumerated over sand, shell, and natural hard bottom reef habitats in the north-central Gulf of Mexico (GOM) off Alabama on quarterly cruises over a two-year period with a baited stationary underwater video camera array. Red snapper showed both significantly higher abundance and larger size over the reef habitat; however, no seasonal effects were observed, indicating temporal abundance patterns were consistent among seasons. Fish assemblages differed among habitats, with significant differences between reef and shell assemblages. Efforts to identify the species that most contributed to these differences indicated that the red snapper accounted for 59% of the overall similarity within the reef fish assemblage and 20% of the total dissimilarity between the shell and reef fish assemblages. This study highlights the utility of applying video techniques to identify the importance of sand, shell, and reef habitat types both to different life stages of red snapper, and to the different fish assemblages occupying distinct habitats in the north-central GOM.

Introduction

Underwater video camera arrays have become an increasingly common tool for characterizing marine fish assemblages (Gledhill et al. 1996; Willis and Babcock 2000; Willis et al. 2000; Gledhill 2001; Rademacher and Render 2003; Cappel et al. 2004) and index-

ing abundances of a single species over a particular habitat type (Ellis and DeMartini 1995). This technique and other video methods are particularly desirable for estimating fish abundance when depth constraints and physical complexity of the bottom topography exist (Bortone et al. 1986; Greene and Alevizon 1989). However, difficulties associated with video censuses exist, such as biased estimates due to poor visibility, difficulty in species identification, fish movement, and

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under-representation of small, cryptic species (Sale and Douglas 1981; Bohnsack and Bannerot 1986). Nevertheless, video methods offer unique advantages over more traditional methods (e.g., otter trawls, scuba surveys) of assessing relative fish abundance as they are nondestructive and the equipment can be deployed and retrieved rapidly from depth.

A variety of habitat types that support a diverse assemblage of fishes exists on the north-central Gulf of Mexico (GOM) continental shelf. The shelf is composed primarily of sand, mud, and silt with little or no vertical relief (Ludwick 1964; Kennicutt et al. 1995). Several studies have characterized fish assemblages over low-relief mud and sand habitats (Moore et al. 1970; Franks et al. 1972; Chittenden and McEachran 1976) while others have characterized shelf-edge bank fish assemblages from the western GOM Flower Garden Banks (Dennis and Bright 1988; Rooker et al. 1997; Gledhill 2001) to the eastern GOM Florida Middle Grounds (Smith et al. 1975; Gledhill 2001). However, extensive low-relief (cm to m) shell ridges at 20–40 m depths exist in the north-central GOM as the result of alternating periods of sea level during the Holocene transgression (Schroeder et al. 1995; McBride et al. 1999; Dufrene 2005). In addition, natural hard bottom habitats in the form of reef pinnacles, banks, and ledges exist on the shallow inner-shelf; these have been suggested as important reef habitat for red snapper and other reef fishes (Parker et al. 1983; Schroeder et al. 1988). However, little information exists regarding the function of these shell ridges and natural reefs due to long held misconceptions that little or no natural hard bottom reef habitat existed on the shallow (<40 m) north-central GOM shelf.

Red snapper, *Lutjanus campechanus*, is a demersal reef fish predominantly found along the continental shelf out to the shelf edge from North Carolina to the Yucatan Peninsula, including the GOM, but not the Caribbean Sea

(Hoese and Moore 1998). Studies characterizing habitat preference of age 0 red snapper have found that they are not randomly distributed on low-relief mud and sand habitats, but that age 0 red snapper have an affinity for low-relief structure such as shell-rubble habitat (Szedlmayer and Howe 1997; Szedlmayer and Conti 1999; Patterson et al. 2005). Older sub-adult and adult red snapper are found in association with mid- to high-relief shelf features such as coral reefs, shelf-edge banks, and rock outcroppings, as well as artificial structures such as artificial reefs, petroleum platforms, and submerged wreckage (Bradley and Bryan 1975; Moseley 1966; Szedlmayer and Shipp 1994). To date, most studies investigating habitat use of red snapper have focused on mud, sand, shell, and artificial structures (Moseley 1966; Bradley and Bryan 1975; Holt and Arnold 1982; Workman and Foster 1994; Szedlmayer and Howe 1997; Szedlmayer and Conti 1999; Rooker et al. 2004; Patterson et al. 2005). However, no studies have examined habitat use patterns of juvenile and adult red snapper in conjunction with associated fish assemblages over shell ridges and natural hard bottom reefs in the shallow north-central GOM.

The objective of this study was to estimate relative abundances of red snapper and associated fish assemblages over different habitat types with underwater video methodology. Specifically, we sought to assess the efficacy of using the video methodology to investigate abundance and size-specific habitat use of red snapper among sand, shell, and natural hard bottom reef habitats. Our goal was to then delineate the relative importance of these habitats to different life stages of red snapper and the associated fish assemblage.

Methods

Study Area

Video work was conducted at sand, shell, and natural reef habitats in the north-

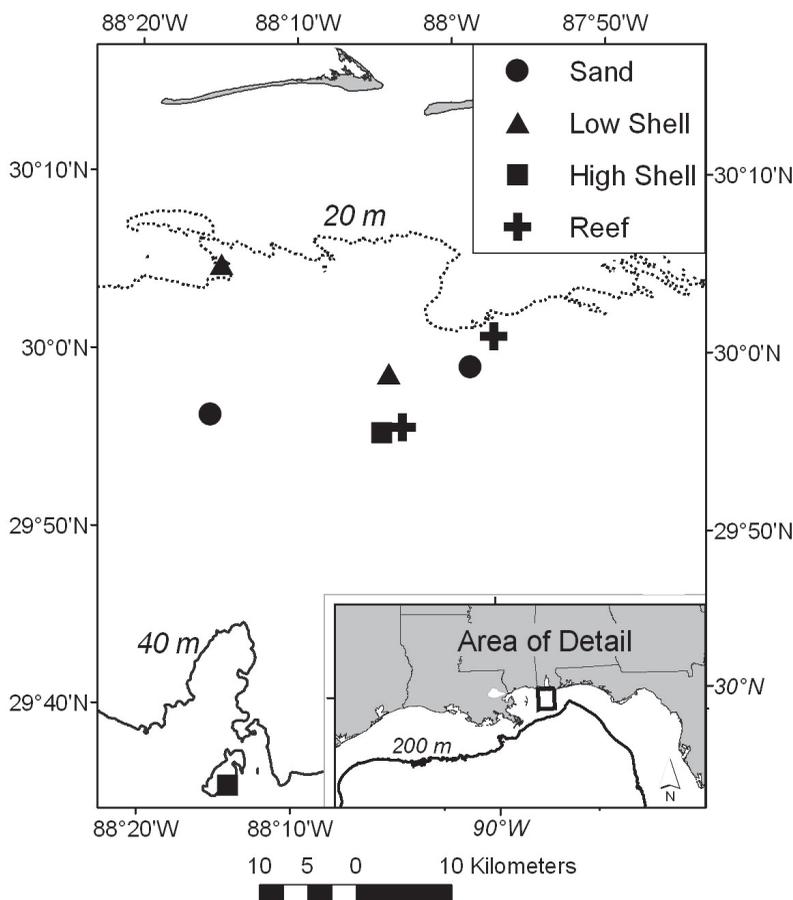


Figure 1. Map of the video study site locations in the north-central GOM. The 20 and 40 m depth contours are shown with the 200 m depth contour within the locator map representing the shelf edge.

central GOM on the Alabama and Mississippi inner continental shelf (Figure 1). Seabed characterization of the region was recently performed with digital side-scan sonar and with sediment box cores to ground truth habitat type (Dufrene 2005). Eight sampling sites were chosen for this study; these included two low-relief (cm) sand sites, four low-relief (cm to m) shell-ridge sites (2 low shell abundance and 2 high shell abundance), and two high-relief (2–4 m) natural hard bottom reef sites (Figure 1).

Video estimation

Sampling was conducted quarterly during 2004 and 2005 with a 4-camera underwater video array. The camera array consisted of four Sony DCR-VX1000 digital video camcorders housed in aluminum underwater housings. Cameras were positioned orthogonally to one another at a height of 25 cm above the bottom to provide a nearly 360° view. Each camera had a 72.5° viewing angle with an approximate viewing distance of 5 m, resulting in an estimated viewing volume of 70.4 m³ (Rademacher and Render 2003). A series of experiments over different depths and light transmissivities was conducted by Gledhill and Lyczkowski-

Shultz (1994) to determine the accuracy of fish identification and measurements using a similar camera array. They concluded that high accuracy at 5 m from the camera was attained when the transmissivity exceeded 75%, which occurred in all of our samples, thus we were comfortable with the 5 m estimate of distance viewed. Two parallel beam lasers placed 10 cm apart were attached below each camera to aid in estimating lengths of observed fish to the nearest cm. The array was deployed for a 30-min period and was baited with a single Atlantic menhaden *Brevoortia tyrannus*, which was replaced after each deployment. All video samples were taken during daylight hours (30 min after sunrise to 30 min before sunset). Water mass characteristics were measured with a Sea-Bird SBE-25 CTD during the camera array soak period. Measurements included temperature, salinity, depth, dissolved oxygen content, and optical backscatter (or transmissivity) to gain an estimate of visibility.

Trawl sampling was also conducted adjacent to all video sites during the same seasons to obtain habitat-specific relative abundance estimates of juvenile red snapper and associated fish assemblages. Therefore, video data was compared to concomitant trawl data to obtain size-specific selectivity bias by gear type using the ratio of length-specific abundance estimates from the trawls relative to the video (Lauth et al. 2004). In addition, to investigate whether gear type biased our fish assemblage results, similar ratios correcting for the abundance-at-size by gear type and habitat type were made for those species that most contributed to the fish assemblages. Further investigation indicated that the corrected abundance-at-size did not affect our results, thus demonstrating the robustness of our fish assemblage results.

Statistical Analysis

A continuous 20 min segment of one tape was examined for fish abundances at each deployment. Tapes were chosen based upon the

optimal view of the habitat of interest combined with the best visibility (i.e., in focus, good orientation relative to the current). Gledhill (2001) determined this continuous 20 min method to be optimal for reducing error in abundance estimates for sampling the taxa present, and for minimizing logistical constraints such as available time at sea. Start time began once the camera array was on the bottom and after sufficient time elapsed for the water column to clear. All fish were identified to the lowest possible taxonomic level and counted. The minimum count (*MIN*), the maximum number of a species observed at any one time on the tape, was used for all statistical comparisons. This method is commonly used for gregarious species, such as red snapper, and is analogous to the *MAXNO* of Ellis and DeMartini (1995), the *MAX* of Willis and Babcock (2000), and the *MaxN* of Cappo et al. (2004). Estimates of total length (TL) were made only at *MIN* counts to eliminate repeated measurements of the same fish. Maximum counts (*MAXIM*) were also made to obtain total counts of each fish species seen over the 20 min segment of the tape analyzed.

Video counts of red snapper were modeled with a Poisson distribution. Specifically, a log-linear fixed effects model using the GENMOD procedure in SAS was used to predict red snapper numbers, with season and habitat as factors (Willis and Babcock 2000; Willis et al. 2000) (SAS Institute, Inc. 2002). The model fit was evaluated with a maximum likelihood method and analysis of deviance. In addition, red snapper length comparisons among seasons and habitats were evaluated separately with a Kruskal-Wallis one-way analysis of variance (ANOVA) on the ranks due to the lack of normality and homogeneity of variance assumptions required by ANOVA (Systat software, Inc. 2004). Dunn's test was used to determine *a posteriori* differences among means ($\alpha = 0.05$).

Fish assemblage data were analyzed with the PRIMER (Plymouth Routines in Multivar-

iate Ecological Research) statistical package (Clarke and Warwick 2001). This nonparametric multivariate analysis used a Bray-Curtis similarity matrix to construct similarities among samples from different habitats and seasons. Fish that were not identified to species and those with a total count of one were excluded from all statistical analyses. Therefore, twenty-five species representing 85% of the overall fish assemblage were included in the statistical analyses. A nonmetric multidimensional scaling (MDS) method was used to map the sample interrelationships in an ordination. The ANOSIM (Analysis of Similarities) permutation procedure was used to test for significant differences of fish assemblages among habitats and seasons (Warwick et al. 1990a).

To assess species-specific contributions, SIMPER (Similarity Percentages) was used as the *post hoc* analysis to indicate the contribution of a particular species to the overall fish assemblage similarity (within season or habitat) and dissimilarity (among seasons and habitats) (Clarke 1993). A cutoff percentage of 90% was used to determine those species accounting for 90% of the total similarities and dissimilarities. Additionally, a stepwise data reduction procedure, BV-STEP, was used to determine which group of species accounted for the observed patterns in the fish assemblage (Clarke and Warwick 1998). This procedure used a Spearman rank correlation coefficient of 95% as a cutoff to determine which group of species together explained most of the variability.

Patterns of species diversity among habitats and seasons were investigated with DIVERSE (Warwick et al. 1990b). This method used the Shannon diversity (H') and Pielou's evenness (J') indices. Diversity measures were estimated with the following equations:

$$H' = -\sum_i p_i \log(p_i)$$

where p_i is the proportion of the total count

from the i^{th} species,

$$J' = H' / \log S$$

where S (species richness) is the total number of species present in the sample. Effects of habitat and season on the diversity indices were analyzed with a two-factor ANOVA (ANOVA) (Systat software, Inc. 2004).

Species abundances and environmental correlations were investigated with canonical correspondence analysis (CCA) by using the CANOCO program (ter Braak and Smilauer 2002). This analysis is designed to maximally correlate environmental variables with fish assemblage data with a nonlinear weighted averaging method. A global permutation test with Monte Carlo permutations was used to investigate the statistical significance between the species abundances and environmental variables. Inter-set correlations of the environmental variables with the axes were used to assess the relative importance of environmental variables. These correlations are the correlation coefficients between the environmental variables and the species-derived sample scores, and are more robust to collinearity than are canonical coefficients (ter Braak and Smilauer 2002). Interset correlation coefficients with absolute values greater than or equal to 0.4 were interpreted as ecologically important (Hair et al. 1984; Rakocinski et al. 1996). Temperature, salinity, depth, and dissolved oxygen were the continuous environmental variables used and habitat types were coded as nominal variables (sand, shell, and reef). In addition, the same 25 species used for previous fish assemblage analyses were used in the CCA to reduce the bias associated with rare taxa.

Results

Forty-two (12 sand, 17 shell, and 13 reef) of the 64 possible video sampling op-

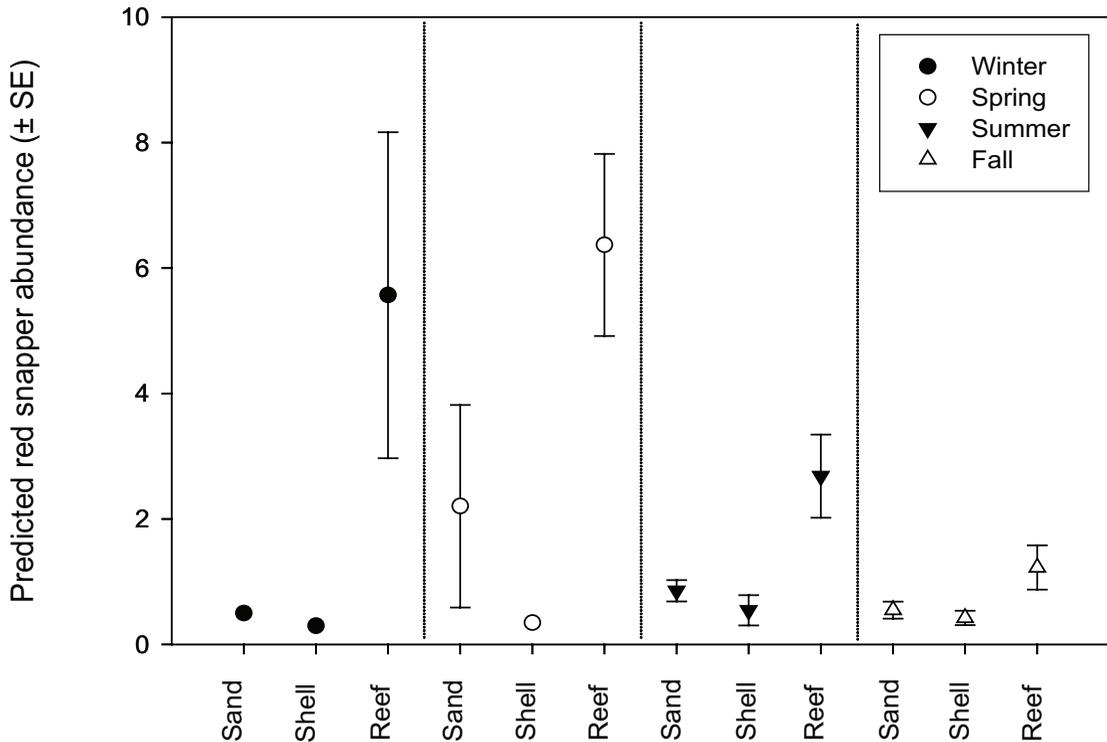


Figure 2. Relative abundance estimates of red snapper, *Lutjanus campechanus*, (± 1 SE) predicted by log-linear model over sand, shell, and reef habitats by season. Relative abundance is expressed as the MIN count of red snapper 20 min^{-1} deployment.

portunities were achieved; no 2005 winter cruise was taken due to inclement weather.

Red Snapper

Relative abundance estimates of red snapper from the MIN index showed significant differences in abundances among habitat types ($P = 0.0318$) (Figure 2). Higher abundance estimates were observed over reef habitat than over either shell or sand habitats. In contrast, seasonal differences in abundance estimates were negligible ($P = 0.8224$), as was the interaction between habitat and season ($P = 0.1260$). Nevertheless, a general trend of higher abundance estimates over the reef was observed in the winter and spring followed by a decline in the summer and fall.

Size differences among red snapper were observed both spatially and temporally. Red snapper found over the reef habitats were significantly longer than conspecifics found over the sand (Dunn's Method; $P < 0.05$) (Table 1). Shell habitats supported intermediate-sized red snapper, but these showed no significant differences in length with red snapper over sand and reef habitats (Table 1). Due to insufficient numbers of red snapper observed on sand and shell habitats over all seasons, only the reef habitat was investigated for a seasonal size effect. A significant seasonal size difference existed, with the largest red snapper observed over the reef during the summer season ($P = 0.002$) (Table 1). Progressively smaller red snapper were seen over subsequent seasons in the fall, winter, and spring (Table 1).

Table 1. Average sizes (TL in mm \pm 1 SE) of red snapper observed over sand, shell, and reef habitats. Average seasonal lengths are displayed for the reef habitat. Habitats and seasons with significantly different sizes are represented by different letters and no differences are represented by similar letters ($P < 0.05$).

		Average size	Differences
Habitat	Sand	12.3 (0.30)	A
	Shell	15.0 (0.20)	AB
	Reef	25.0 (0.43)	B
Season (Reef)	Winter	25.0 (1.34)	A
	Spring	19.2 (1.67)	B
	Summer	31.5 (0.76)	A
	Fall	28.3 (6.67)	A

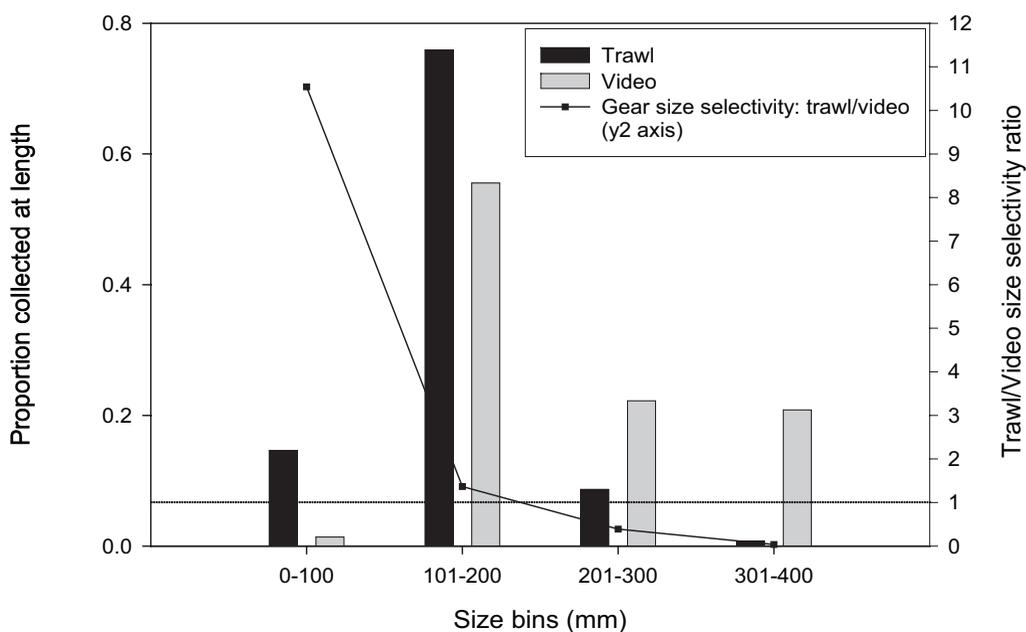


Figure 3. Size selectivity bias of red snapper, *Lutjanus campechanus*, collected with trawl and observed with underwater video methodology. Left axis represents the proportion-at-length of red snapper collected using each gear type. Right axis represents the ratio of the proportion-at-length collected from the trawl relative to the video gear using four size bins (<100 mm, 101–200 mm, 201–300 mm, and >300 mm TL). The dotted line represents a 1:1 ratio of red snapper observed in trawls relative to the video method, which would indicate no gear bias.

Table 2. Total number of fish observed from video estimates arranged in order of decreasing abundance by *MIN*. *MIN* is the maximum number observed at any one time, *MAXIM* is the total number observed over the entire tape, *n* is the frequency of occurrence (out of 42 camera deployments), and total length TL (\pm SE) is the average size of each species. Sizes were not estimated for unidentified fish, thus NA (not applicable).

Taxon	Common name	MIN	MAXIM	n	TL (\pmSE)
<i>Stenotomus caprinus</i>	Longspine porgy	141	2699	24	9.3 (0.2)
<i>Diplectrum bivittatum</i>	Dwarf sand perch	78	889	26	5.8 (0.3)
<i>Lutjanus campechanus</i>	Red snapper	72	1206	18	21.6 (1.1)
Carangidae	Family Carangidae	44	116	4	9.6 (0.6)
<i>Haemulon aurolineatum</i>	Tomtate	28	187	7	22.3 (0.9)
<i>Caranx crysos</i>	Blue runner	27	64	5	26.2 (2.2)
<i>Micropogonias undulatus</i>	Atlantic croaker	25	654	6	10.5 (0.5)
<i>Trachurus lathamii</i>	Rough scad	25	132	5	7.4 (0.7)
<i>Diplectrum formosum</i>	Sand perch	22	83	15	8.1 (0.7)
Bothidae	Family Bothidae	16	26	14	17.9 (1.6)
<i>Centropristis ocyurus</i>	Bank sea bass	14	102	12	11.1 (1.0)
<i>Syacium papillosum</i>	Dusky flounder	13	62	8	14.8 (2.0)
<i>Lutjanus synagris</i>	Lane snapper	10	27	5	21.0 (2.1)
Unidentified fish	Unidentified fish	7	26	7	NA
<i>Menticirrhus americanus</i>	Southern kingfish	6	25	3	12.2 (1.3)
<i>Eucinostomus gula</i>	Silver jenny	5	28	4	10.4 (1.0)
<i>Rhomboplites aurorubens</i>	Vermilion snapper	5	22	1	15.0 (0.0)
<i>Xyrichtys novacula</i>	Pearly razorfish	4	47	3	3.3 (1.0)
<i>Balistes capriscus</i>	Gray triggerfish	4	14	3	23.8 (1.3)
Sciaenidae	Family Sciaenidae	4	12	4	15.0 (2.9)
<i>Leiostomus xanthurus</i>	Spot	4	6	2	13.3 (1.8)
<i>Halichoeres radiatus</i>	Puddingwife	3	13	3	15.0 (2.9)
<i>Centropristis philadelphica</i>	Rock sea bass	3	7	3	8.7 (4.1)
<i>Orthopristis chrysoptera</i>	Pigfish	3	5	3	10.7 (2.3)
<i>Ophichthus puncticeps</i>	Palespotted eel	3	3	2	4.7 (0.3)
<i>Mycteroperca microlepis</i>	Gag grouper	2	15	1	35.0 (0.0)
<i>Chloroscombrus chrysurus</i>	Atlantic bumper	2	6	2	15.0 (5.0)
<i>Decapterus punctatus</i>	Round scad	2	5	1	10.0 (0.0)
Ophidiidae	Family Ophidiidae	2	5	1	15.0 (0.0)
Ophichthidae	Family Ophichthidae	2	3	2	6.0 (4.0)
Triglidae	Family Triglidae	2	3	2	15.0 (5.0)
<i>Archosargus probatocephalus</i>	Sheepshead	2	2	1	33.0 (0.0)
<i>Prionotus rubio</i>	Blackwing searobin	1	8	1	35.0 (0.0)
<i>Brevoortia patronus</i>	Gulf menhaden	1	7	1	15.0 (0.0)
<i>Sphoeroides parvus</i>	Least puffer	1	4	1	1.0 (0.0)
<i>Calamus leucosteus</i>	Whitebone porgy	1	3	1	10.0 (0.0)
<i>Serranus phoebe</i>	Tattler	1	3	1	2.0 (0.0)
<i>Gymnothorax nigromarginatus</i>	Blackedge moray	1	2	1	15.0 (0.0)
<i>Halichoeres bivittatus</i>	Slippery dick	1	2	1	5.0 (0.0)
Carcharhinidae	Family Carcharhinidae	1	1	1	60.0 (0.0)
<i>Sphyaena guachancho</i>	Guaguanche	1	1	1	20.0 (0.0)

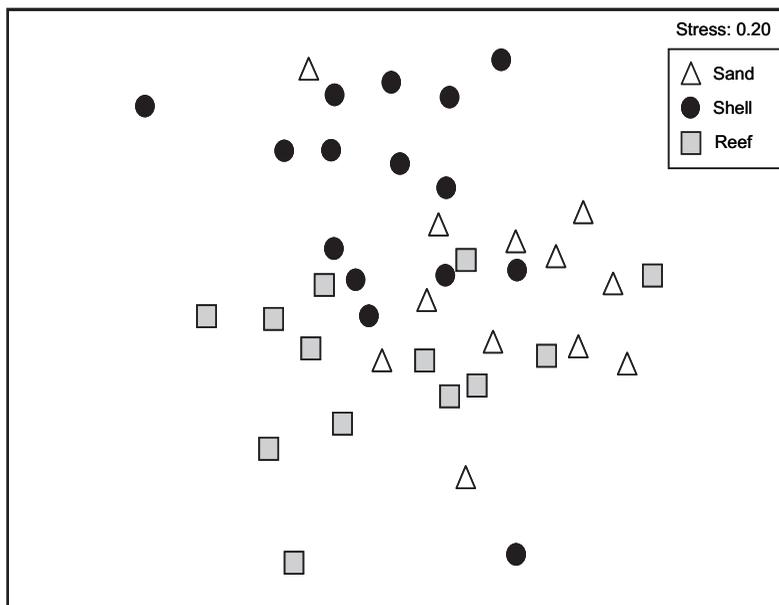


Figure 4. Multi-dimensional scaling (MDS) plot of all samples over the two-year study period. Each sample represents the 25 species analyzed for the fish assemblage.

Table 3. SIMPER results of the species that most contributed to the within-habitat similarity for each of the three habitat types: sand, shell, and reef. Mean abundance of important species within habitat type, the contribution (SIM) to the average within similarity, and the average within similarity/standard deviation (SIM/SD) ratio. A 90% cut-off was used for the cumulative % contribution of species.

Habitat	Species	Mean	SIM	SIM/SD	% contribution	% cumulative contribution
Sand	Longspine porgy	7.42	20.26	1.15	73.12	73.12
	Dwarf sand perch	0.75	3.19	0.51	11.52	84.64
	Sand perch	0.50	1.36	0.39	4.92	89.56
	Red snapper	1.17	0.81	0.31	2.93	92.49
Shell	Dwarf sand perch	3.60	11.63	1.02	58.51	58.51
	Sand perch	0.80	2.26	0.43	11.37	69.88
	Longspine porgy	1.07	2.25	0.42	11.31	81.19
	Dusky flounder	0.47	1.06	0.26	5.32	86.51
	Lane snapper	0.60	0.74	0.21	3.72	90.23
Reef	Red snapper	3.92	15.23	1.11	58.71	58.71
	Longspine porgy	2.77	5.72	0.47	22.05	80.77
	Dwarf sand perch	1.15	2.44	0.40	9.40	90.16

Table 4. SIMPER results of the species that most contributed to the dissimilarity between shell and reef habitats. Mean abundance of important species within habitat type, the contribution (DIS) to the average dissimilarity, and the average dissimilarity/standard deviation (DIS/SD) ratio. A 90% cut-off was used for the cumulative % contribution of species.

Species	Mean _{shell}	Mean _{reef}	DIS	DIS/SD	% contribution	% cumulative contribution
Red snapper	0.47	3.92	16.65	1.22	19.69	19.69
Dwarf sand perch	3.60	1.15	13.35	0.90	15.78	35.47
Longspine porgy	1.07	2.77	12.27	0.98	14.51	49.98
Tomtate	0.07	2.08	6.13	0.53	7.25	57.23
Blue runner	1.40	0.31	5.27	0.42	6.23	63.46
Rough scad	0.53	0.69	4.16	0.37	4.92	68.38
Sand perch	0.80	0.31	4.05	0.76	4.79	73.17
Dusky flounder	0.47	0.31	3.95	0.49	4.67	77.84
Atlantic croaker	0.07	1.15	3.23	0.32	3.82	81.66
Lane snapper	0.60	0.08	2.57	0.56	3.05	84.70
Bank sea bass	0.33	0.38	2.43	0.72	2.88	87.58
Vermilion snapper	0.00	0.38	1.66	0.28	1.96	89.54
Southern kingfish	0.00	0.31	1.61	0.35	1.90	91.44

Size selectivity bias of the video gear was observed for red snapper. Proportions of small red snapper were underrepresented using the video method. The gear size selectivity ratio of small red snapper collected in trawls relative to video estimates indicated that on average 10.5 (<100 mm TL) and 1.4 (101–200 mm TL) red snapper were collected in trawls relative to one red snapper observed using the video method (Figure 3). In contrast, large red snapper were more abundant in the video estimates compared to the trawled counts with 0.4 (201–300 mm TL) and 0.04 (>300 mm TL) red snapper collected in trawls relative to one red snapper seen with the video method (Figure 3).

Fish Assemblage

Thirty-three species representing 16 families were positively identified in this study (Table 2). Unidentifiable taxa were distributed among seven families and an unidentified fish category. A group of seven species best characterized the observed fish assemblage patterns shown with the BV-STEP procedure: blue runner *Caranx crysos*, bank

sea bass *Centropristis ocyurus*, dwarf sand perch *Diplectrum bivittatum*, sand perch *D. formosum*, red snapper *Lutjanus campechanus*, longspine porgy *Stenotomus caprinus*, and dusky flounder *Syacium papillosum* accounted for 95.0% of the correlation among species and the observed patterns detected in the fish assemblages.

Fish assemblages showed differences among the three habitat types (Figure 4). The two-way ANOSIM indicated a significant habitat effect among fish assemblages ($P = 0.008$). Further examination indicated that fish assemblages over the reef and shell habitats differed significantly ($P = 0.006$). However, there were no seasonal differences in fish assemblages within habitats during our two-year study period ($P = 0.299$).

Table 3 shows the SIMPER results for species that contributed most to the overall similarity within habitat type. The longspine porgy accounted for 73.1% of the cumulative species similarity within the sand habitat, the dwarf sand perch accounted for 58.5% for the shell habitat, and the red snapper represented 58.7% of the similarity within the reef habitat. The longspine porgy, dwarf sand perch, and red snapper SIM/SD values were 1.15, 1.02,

and 1.11, respectively. The SIM/SD ratios exceeding 1.0 indicates that each of the three species consistently contributed to the within habitat similarity among samples (Clarke and Warwick 2001). These three species were also important in discriminating fish assemblages between reef and shell habitats. Table 4 shows the total contribution of each species to the dissimilarity between habitat types; the three dominant species together accounted for 50% of the overall dissimilarity. The red snapper contribution was the highest at 19.7%, followed by that for dwarf sand perch (15.8%), and longspine porgy (14.5%). The red snapper most consistently contributed to these dissimilarity differences based upon the DIS/SD value of 1.22.

Habitat diversity indices varied by habitat, with highest species richness, evenness, and diversity associated with the reef fish assemblage (Table 5). Species evenness and diversity were lowest for the sand fish assemblage with increasing values over the shell habitat. However, no significant differences were detected among habitat-specific indices. Similar trends were observed by season, with the lowest values of all three indices during the winter. Species richness increased to a stable maximum over the remaining seasons, while species evenness and diversity peaked in the fall (Table 5). Similarly, no significant seasonal effects were detected among indices.

Environmental variables correlated well with species from the fish assemblages (Table

6; Figure 5). The global permutation test indicated a significant effect of CCA axis 1 ($P = 0.002$) and of all axes combined ($P = 0.002$), thereby indicating a significant relationship between species abundance and environmental variables. The first two CCA axes accounted for 62.5% of the cumulative percentage of the species-environment relationship. Shell and reef habitats correlated well with CCA axis 1, while depth, sand, and shell correlated strongly with CCA axis 2 (Table 6). Caution should be applied when interpreting nominal habitat variables in relation to CCA axes because the interset correlation coefficients are not useful (ter Braak and Smilauer 2002). Thus, nominal habitat variables were used to convey species-specific habitat use information. Species that displayed a specific habitat affinity appeared to correlate well with the corresponding nominal habitat variable (Figure 5). Red snapper and other reef-associated species were highly correlated with reef habitat type with a high negative score on axis 1. Species primarily found on shell corresponded with increasing salinity and temperature and had high positive scores on axes 1 and 2. Species that were found in association with the sand habitat showed a correlation with increased depth and high dissolved oxygen and loaded negatively on CCA axis 2.

Discussion

This study highlights the efficacy of using video methodology to assess habitat use

Table 5. Average species richness (S), Pielou evenness (J'), and Shannon diversity (H') indices for all habitats and seasons.

		S	J'	H'
Habitat	Sand	4.0	0.608	0.941
	Shell	3.9	0.741	1.046
	Reef	4.3	0.780	1.151
Season	Winter	3.6	0.544	0.827
	Spring	4.2	0.767	1.122
	Summer	4.3	0.640	1.004
	Fall	4.2	0.888	1.231

Table 6. Canonical correspondence analysis (CCA) statistics and inter-set correlations relating environmental variables with CCA axes. Bold values denote variables with absolute value correlations ≥ 0.4 .

Statistics	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Eigenvalues	0.491	0.380	0.214	0.141	
Species-environment correlations	0.887	0.821	0.765	0.713	
Cumulative percentage variance					
of species data	9.5	16.8	21.0	23.7	
of species-environment relation	35.2	62.5	77.8	87.9	
Sum of all eigenvalues					5.18
Sum of all canonical eigenvalues					1.39
Inter-set correlations					
Environmental variables					
Depth	0.2685	-0.5518	0.0566	0.0588	
Temperature	0.3581	0.1259	0.0660	-0.3304	
Salinity	0.1244	0.2233	0.5389	0.0075	
Dissolved oxygen	-0.1395	-0.2579	0.0021	-0.1429	
Sand	0.0582	-0.5508	0.3537	0.3094	
Shell	0.5365	0.5891	0.0154	0.0291	
Reef	-0.5609	-0.0323	-0.3503	-0.3212	

by red snapper and associated fish assemblages in the north-central GOM. The method has its inherent biases (i.e., larger fishes were observed while smaller cryptic fishes were likely missed, effects of bait plumes on abundance estimates); however, it appears to be a practical method to characterize red snapper habitat use over a variety of substrate types. Structurally complex habitat types with high relief, such as natural and artificial reefs, rock outcrops, and petroleum platforms, require noninvasive sampling techniques. In addition, the logistical simplicity of dropping the camera array for a 30 min period makes this an appropriate method if multiple deployments over distant sites are needed, as was the case in this study.

Our study found similar habitat-specific results as others with small, intermediate, and large sized red snapper over sand, shell, and reef habitats, respectively. Juvenile red snapper were predominately collected over low-relief sand habitats, which is consistent with the findings of Rooker et al. (2004) and Patterson et al. (2005). In contrast, both sub-adult and

adult red snapper were found over higher relief habitats such as the shell-rubble and natural hard bottom reef habitats. These findings are consistent with previous studies that have found adult red snapper over high relief habitats such as shelf-edge banks, mid-shelf banks, rock outcrops, coral reefs, and artificial structures (Moseley 1966; Bradley and Bryan 1975; Dennis and Bright 1988; Stanley and Wilson 2000; Gledhill 2001). It has been suggested that red snapper recruit to these high-relief habitats by about 18 months of age or 20 cm TL (Gallaway et al. 1999). Nieland and Wilson (2003), using a fishery independent survey design, found age 2 red snapper between 27.5 and 37.5 cm TL were recruited to petroleum platforms. The largest red snapper observed in the current study (mean = 25 cm TL) were associated with reef habitats, but seasonal differences in length ranged from 19.2 to 31.5 cm TL in the spring and summer, respectively. Therefore, these natural reef habitats on the shallow inner shelf may be functionally important for sub-adult and adult red snapper in the north-central GOM.

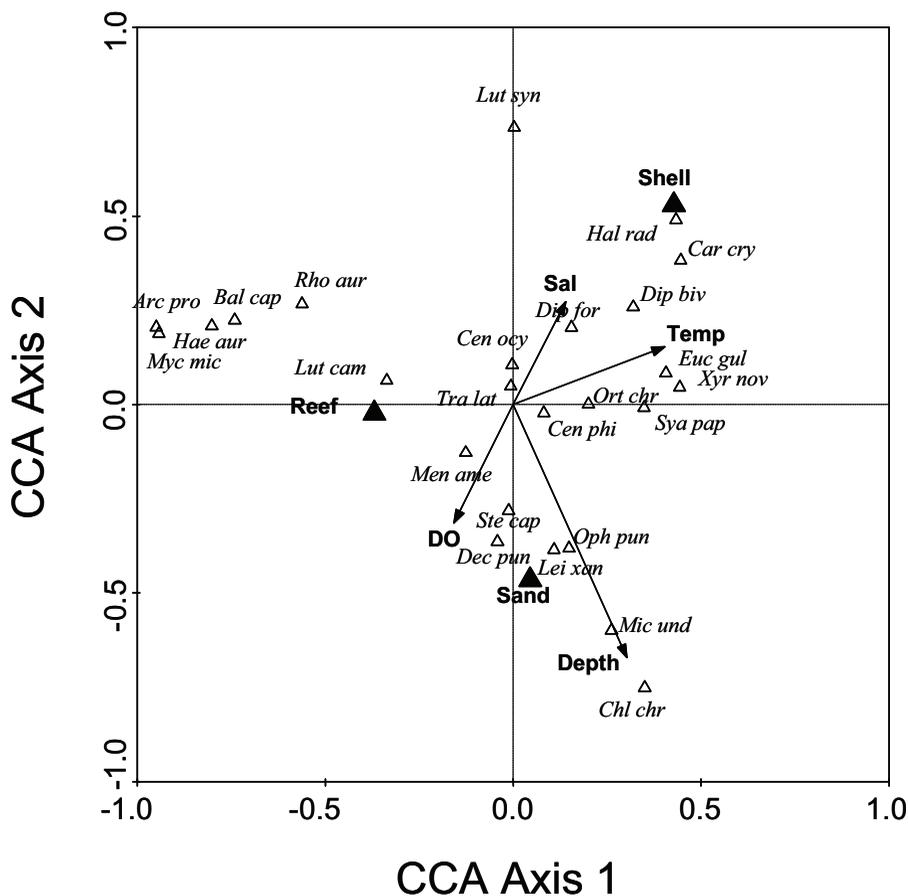


Figure 5. Biplot of axes 1 and 2 from canonical correspondence analysis of fish species and environmental variables. Environmental variables include Depth, Temp = water temperature, Sal = salinity, DO = dissolved oxygen, Sand, Shell, and Reef. Species codes: Sheepshead (*Arc pro* = *Archosargus probatocephalus*), gray triggerfish (*Bal cap* = *Balistes capricus*), blue runner (*Car cry* = *Caranx crysos*), bank sea bass (*Cen ocy* = *Centropristis ocyurus*), rock sea bass (*Cen phi* = *Centropristis philadelphia*), Atlantic bumper (*Chl chr* = *Chloroscombrus chrysurus*), round scad (*Dec pun* = *Decapterus punctatus*), dwarf sand perch (*Dip biv* = *Diplectrum bivittatum*), sand perch (*Dip for* = *Diplectrum formosum*), silver jenny (*Euc gul* = *Eucinostomus gula*), tomtate (*Hae aur* = *Haemulon aurolineatum*), puddingwife (*Hal rad* = *Halichoeres radiatus*), pearly razorfish (*Xyr nov* = *Xyrichtys novacula*), spot (*Lei xan* = *Leiostomus xanthurus*), red snapper (*Lut cam* = *Lutjanus campechanus*), lane snapper (*Lut syn* = *Lutjanus synagris*), southern kingfish (*Men ame* = *Menticirrhus americanus*), Atlantic croaker (*Mic und* = *Micropogonias undulatus*), gag (*Myc mic* = *Mycteroperca microlepis*), palespotted eel (*Oph pun* = *Ophichthus puncticeps*), pigfish (*Ort chr* = *Orthopristis chrysoptera*), vermilion snapper (*Rho aur* = *Rhomboplites aurorubens*), longspine porgy (*Ste cap* = *Stenotomus caprinus*), dusky flounder (*Sya pap* = *Syacium papillosum*), rough scad (*Tra lat* = *Trachurus lathami*).

Seasonal size differences at the reef habitats were likely attributed to emigration and immigration of red snapper. Moseley (1966) observed changes in red snapper abundance at reefs and attributed these movement patterns to passing cold fronts, while Bradley and Bryan (1975) found similar trends and suggested the offshore movement of prey as a potential mechanism. Recent studies have found red snapper exhibit low site fidelity and moderately high dispersal from artificial reefs in the northern GOM (Patterson et al. 2001a; Patterson and Cowan 2003). However, other tagging studies have shown high site fidelity with little movement from artificial reefs in the northern GOM (Szedlmayer and Shipp 1994; Szedlmayer 1997; Szedlmayer and Schroepfer 2005). In particular, Szedlmayer and Schroepfer (2005) found no seasonal movements and long average residence times (218 d when excluding caught fish from analysis) for red snapper on artificial reefs in our study area. However, their study was conducted over a 4 year period and they interpreted long-term residence as any time greater than 117 d. Our interpretation of their Vemco telemetry data, excluding caught fish, indicated only 15.6% of tagged red snapper had residency times greater than 12 months. In addition, 65.6, 43.8, 34.4, and 21.9% of tagged red snapper in their study had residence times less than 9, 6, 3, and 1 month, respectively. Nevertheless, the large size range of red snapper in their study (43.5–84 cm TL) combined with the use of large artificial structures, such as army tanks and cars, may negate a direct comparison to our results.

In this study the largest red snapper were observed over the reef habitat during the summer season, with progressively smaller fish over the following seasons, suggesting that the larger fish were moving away. By spring, the smallest red snapper were observed over the reef, and when combined with previous size-at-age data, suggests that these fish were age 1 individuals that recruited from adjacent

low-relief habitats (e.g., sand, mud, shell ridges) (Szedlmayer and Shipp 1994; Patterson et al. 2001b; Wilson and Nieland 2001). Fishing mortality may be another contributory factor to the observed trends in decreased size of red snapper over the reefs. The summer samples were the first after the recreational fishing season opened on April 21st of both years, and the reef sites sampled in this study are known to local fisherman and have been assigned the names of Southeast Banks and 17 Fathom Hole (Schroeder et al. 1988).

Red snapper abundance estimates at the reefs did not significantly change over the different seasons, suggesting that the large fish may have been replaced by smaller conspecifics. Bailey et al. (2001) performed laboratory studies on the cohabitation of juvenile and of sub-adult red snapper and found that the smaller fish were not allowed to occupy the reef when the larger fish were present. Moreover, Workman et al. (2002) found increased numbers of age 0 red snapper occupied the reefs when age 1 specimens were absent. The general trend of decreasing sizes with little change in relative abundance in this study indicates these smaller fish were likely replacing the larger conspecifics as the latter emigrated off the reef due either to natural movements or to fishing mortality. However, our results are based upon low sample sizes ranging from two reef samples in the winter to four reef samples in both the spring and summer seasons. In addition, a large amount of variability was observed in both our winter and spring estimates, which may influence the lack of any seasonal patterns. Thus, studies that aim to look at fish movement on and off a reef using underwater video methods need to incorporate more replication to gain insight into fish movement patterns.

The longspine porgy, dwarf sand perch, and red snapper were collected over all habitat types; nevertheless, they each appeared to show affinities to sand, shell, and reef habitats, respectively. The longspine porgy has

been reported as one of the most abundant fish species collected over sand and mud habitats off Texas, Louisiana, and Mississippi (Moore et al. 1970; Franks et al. 1972; Chittenden and McEachran 1976; Geoghegan and Chittenden 1982). However, this species is not restricted to these habitats as Parker et al. (1979) found it to be one of the most abundant species on artificial reefs off South Carolina. The longspine porgy was the most ubiquitous species in this study because it was the dominant taxa contributing to the sand assemblage and was one of the most important contributing species to characterize the reef and shell assemblages. Little information exists on the habitat preference of the dwarf sand perch; however, limited studies have found this species' general distribution to be in association with low-relief sand and mud areas (Fraser 1971; Bortone et al. 1981). This study was the first to document the potential importance of shell habitat to the dwarf sand perch based upon its large cumulative contribution toward the shell habitat fish assemblage.

The red snapper was numerically the most dominant reef-associated species in this study. Many studies characterizing both natural and artificial reef fish assemblages have found red snapper to be abundant (Stanley and Wilson 2000; Gledhill 2001; Rademacher and Render 2003); however, no studies have shown red snapper to be the most important species to contribute to the structure of the reef fish assemblage.

The CCA technique is useful both in delineating habitat associations by species and in characterizing fish assemblages based upon habitat type. Species that correlated with the sand habitat type have been previously characterized as utilizing sand habitats. These include the Atlantic croaker *Micropogonias undulatus*, Atlantic bumper *Chloroscombrus chrysurus*, spot *Leiostomus xanthurus*, round scad *Decapterus punctatus*, southern kingfish *Menticirrhus americanus*, and palespotted eel *Ophichthus puncticeps* (Moore et al.

1970; Chittenden and McEachran 1976; Hale 1987; Hoese and Moore 1998; Pierce and Mahmoudi 2001). Additional species, other than the dwarf sand perch, that displayed an affinity for the shell habitat included the sand perch, blue runner, and puddingwife *Halichoeres radiatus*, all of which have been previously documented over a suite of habitat types (Hastings and Bortone 1976; Bortone et al. 1981; Pierce and Mahmoudi 2001). A mutualistic foraging association between the puddingwife and the bar jack, *Caranx ruber*, has been observed (Baird 1993). This social facilitation was also observed with several other species suggesting the blue runner, a close relative of the bar jack, could co-occur with the puddingwife over shell habitats for foraging purposes. All species that showed an affinity to reef habitat type in the CCA biplot were also reef associated. These species included the red snapper, vermilion snapper *Rhomboplites aurorubens*, sheepshead *Archosargus probatocephalus*, gag grouper *Mycteroperca microlepis*, gray triggerfish *Balistes capriscus*, and the tomtate *Haemulon aurolineatum* (Caldwell 1965; Smith et al. 1975; Parker et al. 1979; Sedberry and Van Dolah 1984; Moran 1988; Kellison and Sedberry 1998). Bortone et al. (1997) found the vermilion snapper to be the best indicator species for offshore artificial reef fish assemblages in the northern GOM. In addition, the tomtate has been found to be the most abundant species over rock outcrops at mid-shelf depths of 25–38 m off the South Carolina coast (Sedberry and Van Dolah 1984).

The abundance of several species correlated with environmental variables and these variables may have influenced fish assemblage structure. Depth was the only measured environmental variable that had a correlation coefficient ≥ 0.4 , and both the Atlantic croaker and Atlantic bumper correlated strongly with depth. However, both species were regularly found in shallow inshore waters (<20 m) and were not limited

to deeper offshore waters (Moore et al. 1970; Chittenden and McEachran 1976; Pierce and Mahmoudi 2001). In addition, several species were correlated with temperature, salinity, and dissolved oxygen content. Of notable importance was the longspine porgy with high dissolved oxygen levels and the dwarf sand perch, sand perch, and bank sea bass with high temperature and salinity. The association of the sand perch and bank sea bass with high salinity is consistent with similar analyses investigating species-environmental relationships (Bortone et al. 1997). However, the largest differences in temperature, salinity, and dissolved oxygen within any season during our video sampling were 4.75°C, 1.80 ‰, and 2.53 mg · L⁻¹, respectively. These narrow differences likely contributed to the minimal impacts that the water mass characteristics had on the species distributions and abundances.

The highest diversity indices were associated with the reef fish assemblage. Similar studies using trawl methodology found higher diversity and biomass over hard bottom habitats than over sand bottom (Wenner 1983; Sedberry and Van Dolah 1984). Higher vertical relief with more structural complexity likely provides greater microhabitat space for a suite of different species to occupy. However, our diversity indices were lower than other studies characterizing fish assemblages over natural reef habitats in the GOM (Smith et al. 1975; Dennis and Bright 1988; Rezak et al. 1990; Rooker et al. 1997). Differences in gear type likely contributed to the observed trends as these studies used SCUBA techniques that are capable of better identifying smaller cryptic species and sampling a larger area. Gledhill (2001) used a similar camera array to characterize reef fish assemblages on offshore shelf-edge banks and found much higher diversity indices; differences are likely due to the location and scale of reef habitats. Our reef sites were located on the inner continental shelf at depths between 25 and 32 m

and total reef area is estimated to have ranged from m² to several km² in size. In contrast, the offshore banks Gledhill (2001) analyzed were in average water depths of 63.5 m with area sizes in the hundreds of km².

The underwater video methodology used in this study appeared to be size selective for larger red snapper. In comparing our gear selectivities, assumptions such as independent length-specific values between gear types, negligible variability in estimates, and similar areas sampled between gear types were not met. However, the goal of identifying the sampling bias associated with the video was achieved. Thus, this study revealed habitat use patterns of the largest red snapper utilizing these sand, shell, and reef habitats, while excluding the smallest individuals that the trawl gear was capable of collecting. Results of this size selectivity highlight the importance of using multiple gear types when quantifying fish habitat use patterns and attempting to delineate relative habitat importance.

The goal of this study was to use underwater video methods as a tool to characterize fish assemblages, with an emphasis on red snapper, over distinct habitat types. Results indicated this was a useful technique to identify fish assemblages over different habitat types in the north-central GOM. In addition, this sampling technique appeared to be a practical method for estimating relative abundance and investigating red snapper habitat use over sand, shell, and natural hard bottom reefs.

Acknowledgments

We thank the National Oceanic and Atmospheric Administration-NMFS Pascagoula, MS laboratory for providing field assistance, equipment, and boat time aboard the R/V *Caretta*. A special thanks to Drew Hopper, Kendall Falana, David Saksa, and Kevin Rademacher for their logistical support and

expertise. We also thank Derek Borne, Kevin Boswell, Mark Miller, and Will Patterson for sampling assistance, Yvonne Allen for preparing the study site map, and David Nieland for constructive comments and criticism on manuscript preparations. Funding for this project was provided by National Sea Grant (grant number NA16RG2249).

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