Seasonal and inter-annual changes in offshore reef fish assemblages associated with hydrographic, meteorological and climatic conditions.

Final Project Report
To the

State Recreational Fisheries Advisory Committee (SRFAC)

Prepared By:
South Carolina Department of Natural Resources
Marine Resources Division
217 Fort Johnson Road
Charleston, South Carolina

**FINAL REPORT TO THE SOUTH CAROLINA
STATE RECREATIONAL FISHERIES ADVISORY COMMITTEE (SRFAC)**

For

Seasonal and inter-annual changes in offshore reef fish assemblages associated with
hydrographic, meteorological and climatic conditions.

by

MICHAEL D. ARENDT, CHARLES A. BARANS, JESSICA C. JOHNSON, SUSAN M.
PATE, STEPHEN R. CZWARTACKI, DANY E. BURGESS AND RICK L. HIOTT.
South Carolina Department of Natural Resources
Marine Resources Division
Charleston, South Carolina

2 October 2009

TABLE OF CONTENTS

Table of Tables

Table of Figures

Executive Summary
More than 77,000 short-duration fisheries video data files were remotely collected at a small, un-fished research reef between 1999 and 2008. These data enabled perhaps the most detailed assessment to date of seasonal and annual occurrence of game fishes at a mid-continental shelf reef. Although the reef was actually located off GA, similar fish assemblages would be expected at reefs located the same distance off SC; thus, SRFAC funding to review data from the last two years of the study (when ~60% of the data were collected) had great application to SC fishers.

Observation rates for black sea bass and gray triggerfish increased dramatically during the first half of the study, after which time they decreased to near year one levels. Atlantic spadefish were seasonal visitors to the reef, but also showed a general decline in later years of the study. Snapper and grouper were infrequently observed, but the general trend was also that of decline. Three species (gag grouper, black sea bass and gray triggerfish) may have spawned at the research during this study and a few sheepshead appeared to become established by year eight. Steady increase of reef fishes to the newly created reef followed by a decline (though not a complete disappearance) in observation frequency may reflect the inability for a small reef to support a large multi-species fish assemblage competing for the same resources. Differences in daily activity may have also contributed to less frequent observation of snapper and grouper, especially given that both groups were observed more frequently earlier in the day (grouper) or at certain tide stages (snapper). The magnitude of tidal-induced water level changes at this mid-shelf reef were comparable to changes found inshore, but it is the currents associated with these tide changes (rather than estuarine flushing or threat of going dry) that is likely most important.

Pelagic fishes such as blue runner, amberjacks, Great barracuda, little tunny, cobia and sharks provided nearly year-round predation pressure at the research reef. Blue runner were seen repeatedly throughout the day, but almost exclusively between July and September, particularly on large tidal ranges. Amberjacks and Great barracuda were present in all seasons, and both were more common on flood tide stages (with amberjack also more common in the morning and during the first half of the tide change). Fisheries video data suggested that amberjack and Great barracuda may have over-wintered on the continental shelf rather than returning to south FL. Infrequent observation of cobia in summer 2007 and winter 2008 may also represent sightings of members of a resident, rather than a seasonally migratory, population.

Remote visual monitoring of the reef provided a wealth of information collected in a non-destructive manner (i.e., no fish were killed (except by other fish) in the making of these videos). On some days lots of fish were seen, but the next day it could look like an underwater desert. Only a small percentage of this variability was able to be explained by the co-occurrence of other species and/or environmental variables. Our inability to explain "why" variability occurred in observation trends may be in part due to the sheer volume of observations examined; however, over-simplifying the analytical approach wouldn't yield meaningful results, either. Furthermore, the ability of remote video monitoring to reliably document "who" is present at any given time demonstrates the merit of this methodology. While the specific system used in this study may not be appropriate for use everywhere, the quality and cost of submersible video data loggers has improved greatly, and expanded use of this technology (especially if used with other types of data loggers) could prove incredible beneficial to researchers, managers and fishers in the future.

Background
Following decades of directed efforts by private groups and state agencies alike to enhance fishing opportunities, the phrase "artificial reef" has become synonymous with "fishing". And for nearly as long, researchers have sought to answer the oceanic equivalent of the 'chicken or egg first' debate: do artificial reefs simply attract fish or do they actually promote stock enhancement? The diplomatic answer is "both, depending on the circumstances" because there are a variety of factors that determine a reef's success. Those factors include but are not limited to the target species being evaluated; the amount and type of material placed on the seafloor; where the reef is placed with respect to critical currents for transport of food, larvae and adults; and the magnitude of both natural predation and human fishing pressure. Designing an appropriate research plan to evaluate the successful nature of a reef is equally complex, given that scientific observations must be collected without altering the natural order of life on the reef and that studies need to be conducted over multiple seasons and years to include a variety of environmental conditions. Ideally, the study would also be conducted at a un-fished reef to eliminate the confounding effects of the removal of fish from the reef due to fishing pressure.

In spring 1999, the SC Department of Natural Resources (SCDNR) received a rare opportunity to participate in such a study. In response to a growing interest in the development of Integrated Ocean Observing Systems (IOOS) to provide real-time meteorological and oceanic data, researchers at the Skidaway Institute of Oceanography (SKIO) in Savannah, GA partnered with several regional agencies to establish the South Atlantic Bight Synoptic Observational Network (SABSOON). SABSOON primarily involved recording a physical oceanography data every six minutes at fixed locations on the middle continental shelf off of GA, but the SCDNR's role in the study was to evaluate fish recruitment to and utilization of a small artificial reef established at an un-disclosed location within the SABSOON study area. Given the fine-scale temporal resolution of environmental data collection, SCDNR researchers sought to collect fisheries data with a comparable degree of intensity in order to realize the full capability of an unprecedented fisheries oceanography study. As such, a submersible camera system was fabricated to remotely collect and store short-duration (10-sec) video clips every hour during daylight. The artificial reef was deployed in May 1999 and fisheries video monitoring began three months later.

The use of underwater video to collect data was not a new idea, but what made this study unique was the approach. In contrast to underwater video filmed by SCUBA divers, baited drop cameras or remotely-operated vehicles, the camera system in this study remained at the research site throughout the study which provided two distinct advantages. First, the camera system became part of the reef itself and therefore should not have induced behavioral changes in the fish assemblage during data collection. Second, the data were recorded daily rather than sporadically, increasing the probability of collecting representative data. A similar approach used to study a tropical reef fish assemblage in the Bahamas (Smith and Tyler, 1973) three decades earlier noted distinct periods of activity within and between days for several species; thus, the limitations of only collecting sporadic point-in-time visual surveys should not be underestimated. Although equipment malfunction periodically prevented true daily data collection throughout the nine year study period, the data that were collected and deemed suitable for analyses in this study yielded incredible insights regarding the movement and distribution of several fish species on the middle continental shelf and the potential of fisheries video to play an increasingly important role in monitoring and managing fishes in the future.

Methods
Data collection
A small (~2100 ft^2) research site was established approximately 40 nm off the coast of Georgia. This mid-continental shelf area consists typically of sand bottom habitats separating low relief, "live bottom" sponge/coral or hard-bottom habitats, which are located sporadically throughout the continental shelf of the South Atlantic Bight (Strusaker, 1965).

The primary reef structure was composed of 12 large pyramid-shaped concrete fish habitats (Artificial Reefs Inc.). Each reef unit measured about 8.2 ft wide at the base by 4.9 ft tall, were arranged in six clusters of two structures each and evenly spaced along the perimeter of a 'circle' approximately 45 ft in diameter. Each of the three sides had three triangular-shaped openings, each measuring about 4 in (b) x 8" m (h), which were penetrable by most reef fishes. Visual observation data were collected by six underwater cameras situated on top of a pyramid unit (Figure 1) at the center of the reef circle, approximately 22 ft interior from the outer-edge of the reef-unit clusters (Figure 2).

The video system consisted of two main parts: (1) video cameras inside of a pressure housing located on the sea floor and (2) a remotely located video capture engine. Six small, black and white security cameras (Supercircuts PC-23C) with low light capabilities (< 0.04 lux), wide-angle lenses (8 mm, 12° angle of view), and relatively low resolution (460 lines) were used. The camera housing contained a micro-controller and several basic sensors. The micro-controller multiplexed analog video signals (NTSC RS-170) from each camera to the single coaxial cable running between the pressure housing and the video capture engine (a Windows NT computer). The micro-controller interfaced with a video titler and sensors, while the embedded computer acted as a web server; thus file transfer and system parameter updates were possible at anytime via "PC ANYWHERE" software. A console-controlled video frame grabber then converted analog video signals to digital images.

Digital image data from the bottom-mounted camera system were transmitted by an established microwave linkage to shore (US Navy, Tactical Air Combat Training System), then by a T1 line to the SKIO in Savannah, GA, and by the Internet to the Marine Resources Research Institute (MRRI) of the SCDNR in Charleston, SC. Digital images remain electronically accessible on the Internet (http://fishwatch.dnr.sc.gov).

Data analysis
Each video data file was manually reviewed and all species present were noted. Certainty of proper identification (certain, fairly certain, not certain) and relative abundance (<5, 5-20, or >20 individuals) of each species were also recorded. Overall visibility for the video data file was noted as follows: "good" when the field of view extended beyond the furthest structure present and the structural openings were distinguishable; "fair" when the full extent of the foreground structure present could be seen, but the details of reef unit holes were less distinct, and "poor" when the full extent of the foreground structure was not visible. "Poor" visibility files were excluded from analyses, as were video data files with > 50% fouling of the camera windows regardless of species identification certainty. All data gleaned from review of video data files were stored electronically in a relational data base (MS Access) on a SCDNR server; this data base also provided the basis for the video search features on the FishWatch website.

Generally one video data file per camera was collected each hour; however, because between one and 12 video data files per hour were occasionally collected, the data were standardized to eliminate bias associated with periods when sampling was more rigorous. For each unique day and hour combination (herein referred to as a "day-hr"), the average of relative abundance indices (0 if not seen, 1 to 3 depending on relative abundance when seen) was calculated among replicate video data files to create a single value for each day-hr of the study. This approach enabled replicate observations within each day, which was useful for evaluating the importance of within-day factors such as time of day and tide effects.

Principal components analysis (PCA) was used to visually portray overlap in the temporal occurrence of species of interest, as well as between individual species and a suite of environmental variables. For comparing among species, a daily "abundance index score" was calculated as the average of day-hr averages for each species; this approach reduced the frequency of "0" scores in the data set enabling the development of a clearer picture of co-occurrence trends. For comparing relationships between a given species and environmental variables, each day-hr of the study was used to enable inclusion of time of day and three tidal metrics at the time of video data sampling (percent of tide elapsed, tide stage and tide range). Twenty-five environmental variables were initially evaluated (Table 1); however, only 11 were retained for analyses due to interactions between variables. Subsequent hourly change and inter-daily variations were calculated for several variables to provide a context (i.e., time relative to frontal system passage) for the nature of conditions at the time of video data sampling; however, these metrics were highly correlated with the actual measurement for the variable of interest at the time of video data sampling, so only the actual variable measurements were retained.

Data were not normally distributed; thus, non-parametric Kruskal-Wallis (K-W) rank testing followed by pair-wise comparisons using Dunn's Test was performed using Minitab 15. Species or group-specific hourly average abundance indices for all usable day-hrs in the study were tested for differences among seasons and years. Rank testing for the effects of moon phase (wax, wane) and fraction of the moon illuminated was only performed for days when a species or group was actually observed. Similarly, rank testing for the effects of time of day and tidal metrics was conducted using all day-hrs on days when a given species or group was observed. Descriptive statistics (mean, 10th & 90th percentiles) for bottom water temperature, salinity, wave height and barometric pressure were also calculated for each species or group.

Figure 1. Camera housing used to remotely collect fisheries video data (1999-2008) at a small research site off the coast of GA.
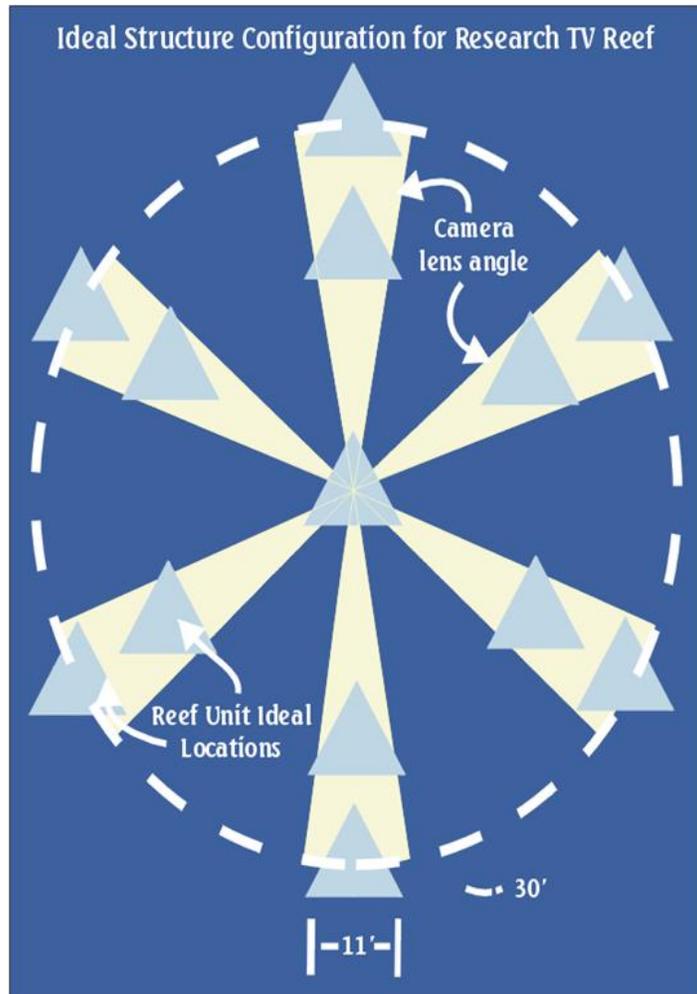
Figure 2. Orientation of camera housing relative to artificial reef units at the research site.

Table 1. Environmental variables used and excluded from Principal Components Analysis.

Retained	
1) Moon fraction illuminated (0-25%; 25.1-50%; 50.1-75%; 75.1-100%)	7) Time of day (07:00-09:00; 10:00-12:00; 13:00-15:00; 16:00-18:00)
2) Moon phase (waxing, waning)	8) Bottom water temperature (degC)
3) Photoperiod (waxing, waning)	9) Bottom water salinity (psu)
4) Range (m) between high and low water	10) Wave height (m)
5) Percent of water level change elapsed	11) Barometric pressure (mB)
6) Tide stage (ebbing, flooding)	

Removed	
1) Daylength (hr)	8) Wind speed (m/s)
2) Season (Jan-Mar; Apr-Jun; Jul-Sep; Oct-Dec)	9) Hourly change in wind speed (m/s)
3) Year (1999-2008)	10) Wind direction (degree)
4) Wave period (s)	11) Hourly change in wind speed (degree)
5) Air temperature (degC)	12) Inter-daily change in wind direction (degree)
6) Hourly change in air temperature (degC)	13) Hourly change in barometric pressure (mB)
7) Inter-daily change in air temperature (degC)	14) Inter-daily change in barometric pressure (mB)

Results Part One: How'd we do? The Extent and Quality of Data Collection
A total of 77,593 video data files were collected during the course of 1,650 sampling days during six years between 1999 and 2008 (Table 2). Fourteen percent (*n*=10,632 video data files) were corrupted and could not be opened for review. Visibility for 50% (*n*=38,735) of video data files was deemed to be "poor" and these videos were excluded from analyses. An additional four percent of video data files (*n*=2,777) collected during periods of acceptable visibility were also excluded due to biological fouling on camera lenses which reduced field of view. Data deemed suitable for analyses consisted of 25,482 video data files collected on 976 distinct days with between one and eleven hours of sampling per day (average = 8.2 hrs per day).

More than 125 listings (excluding unidentified listings) were used to identify fish, invertebrates, a sea turtle (loggerhead, *Caretta caretta*) and even a bird species (common loon, *Gavia immer*) observed at the research site. Identification listings were comprised of 13 categories (Table 3). Reef fishes, pelagic predators, forage/juveniles and sharks accounted for 70% of identification listings and are the only categories considered in this report. Eight reef fishes (14 listings), five pelagic predators (8 listings), sharks (6 listings) forage/juveniles (3 listings) are discussed.

Inability to sufficiently identify species in videos with suitable visibility and negligible fouling excluded an average of 15% of video data files for species or species groups of interest (Table 4). Black sea bass and snappers were most affected by unreliable identifications, with identification-excluded files accounting for 65% and 44% of occurrence of these species under conditions suitable for analyses, respectively. Poor visibility excluded more certain identifications than were lost due to identification problems for nine species during suitable viewing conditions. Except for gray triggerfish (*Balistes capriscus*) and Atlantic spadefish (*Chaetodipterus faber*) less than 3% of good identifications in suitable visibility were lost due to camera lens fouling.

Table 2. Summary of video data files collected and deemed usable.

Year	N days	N files	Usable days	% Usable
1999	102	423	23	22.5
2000	266	3541	125	47.0
2002	89	4627	73	82.0
2004	251	8785	113	45.0
2005	182	5627	137	75.3
2006	124	8928	37	29.8
2007	362	26040	267	73.8
2008	274	19622	201	73.4
Total	1650	77593	976	

Table 3. Summary of species categories used for video data file review.

Category	N listings	% listings	Category	N listings	% listings
reef fish	49	39	benthic	2	2
pelagic predator	21	17	commensal	2	2
small cryptic	17	13	stingray	2	2
forage/juvenile	10	8	bird	1	1
shark	8	6	inshore fish	1	1
invert	7	6	turtle	1	1
jellyfish	5	4			

Table 4. Distribution of observations in videos retained vs. excluded for species/groups.

Species or Species Group	total	Suitable Visibility retained	Suitable Visibility excluded	Suitable Visibility % excluded		Poor Vis	% lost		Fouling	% lost
Sheepshead	74	60	14	19		38	51.4		1	1.4
Gray triggerfish	494	383	111	22		74	15.0		57	11.5
Black sea bass	3881	1377	2504	65		210	5.4		62	1.6
Atlantic spadefish	3208	2587	621	19		1431	44.6		215	6.7
Tomtate	10195	9324	871	9		3750	36.8		235	2.3
Snappers	377	212	165	44		40	10.6		4	1.1
Groupers	2791	2178	613	22		305	10.9		30	1.1
Vermilion snapper	3466	2885	581	17		1607	46.4		77	2.2
Amberjacks	1366	1307	59	4		226	16.5		21	1.5
Great barracuda	955	754	201	21		199	20.8		22	2.3
Blue runner	1278	1131	147	12		453	35.4		16	1.3
Requiem sharks	127	113	14	11		29	22.8			0.0
Cobia	89	69	20	22		15	16.9		2	2.2
Little tunny	190	163	27	14		17	8.9		2	1.1
Forage/Juveniles	10402	10204	198	2		6214	59.7		210	2.0
Scad	5114	4635	479	9		2340	45.8		112	2.2

Total   *44007*   *37382*   *6625*

Results Part Two: Attraction, Production…or Both?

Benthic game fish species such as black sea bass, gray triggerfish, Atlantic spadefish, sheepshead, snappers and groupers were observed with significantly greater (Appendix 1) frequency and abundance between January and June than during July to December (Figure 3). Inter-annual differences were also noted for this group of fishes in all seasons, with increasing abundance indices between 1999 and 2004 followed by significant decreases between 2004 and 2008. The decrease in abundance indices for these fishes during the second half of the study may have reflected less time spent at this small reef as its resources became insufficient to support a large resident group of fishes. However, coincident with the decline in abundance we also received reports that our 'secret reef' had been discovered by at least one spear fisher who may have removed (and continued to remove after being asked not to) reef fishes from this small research site. If the latter scenario indeed occurred, the reef may have served to produce fish (particularly black sea bass and gray triggerfish) during the first half of the study, but also negatively attracted them for exploitation during the second half of the study.

In contrast, relative abundance indices for tomtate and vermilion snapper (Figure 4) and small forage and juvenile fishes (Figure 5) increased significantly between 1999 and 2008, all of which were observed with greatest frequency and abundance between July and December. Juvenile fishes were not consistently identified, but juvenile tomtate and vermilion snapper were regularly noted when fish occurred in close proximity to the camera; thus, the small research reef appeared to contribute to production for at least these two species. Abundance indices for pelagic predators (sharks, little tunny, cobia, blue runner, amberjacks and barracuda) were also significantly greater between July and December; however, a net decline in abundance indices for this group was observed between 1999 and 2008 (Figure 6). Abundance indices for January to March were almost exclusively attributed to little tunny.

6
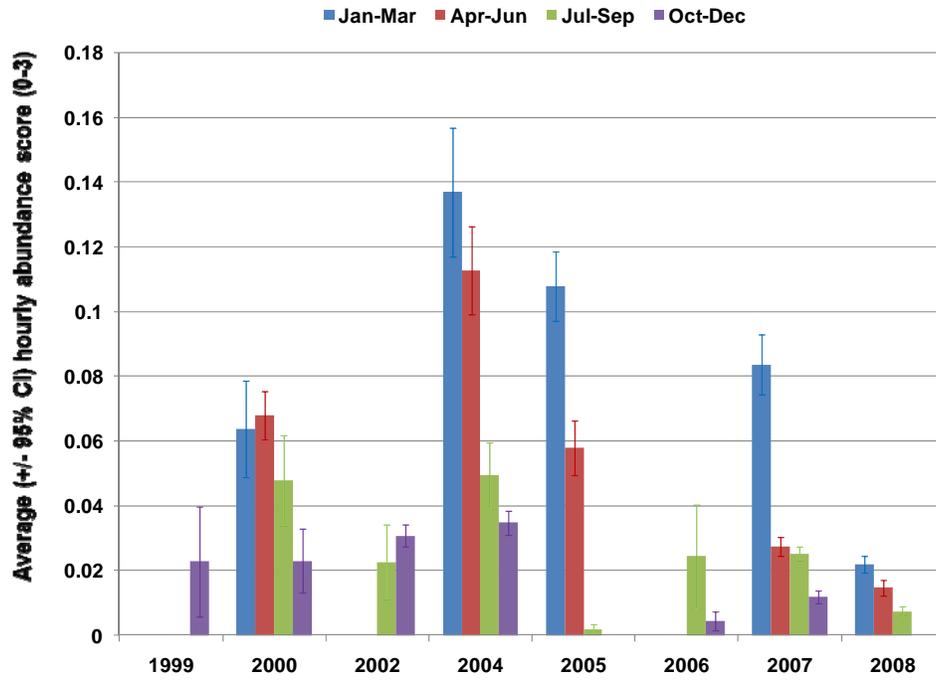
Figure 3. Seasonal and inter-annual observation trends for benthic game fishes.
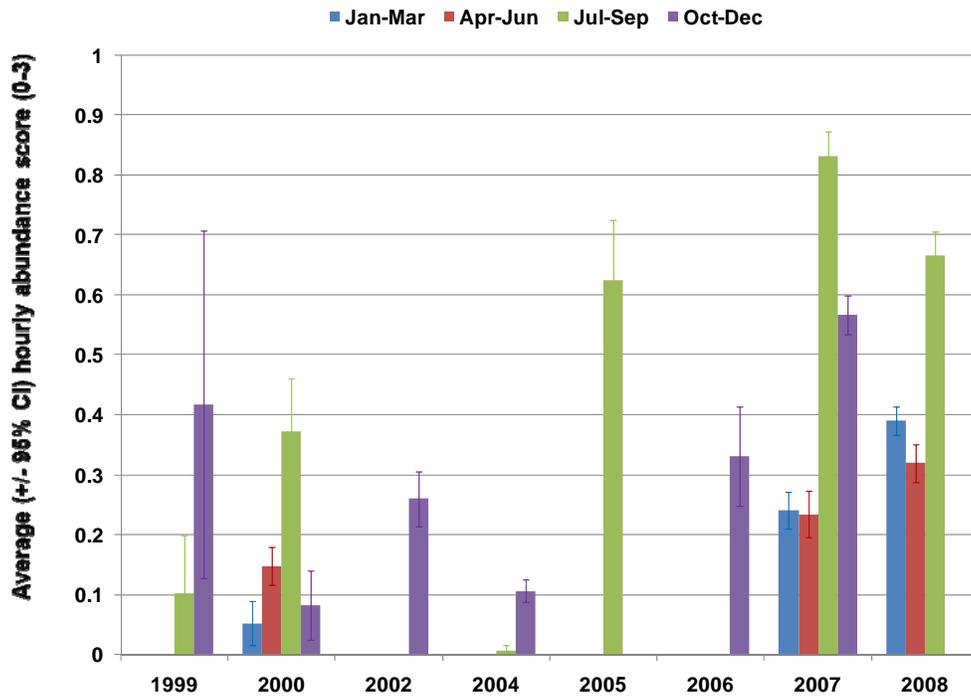
Figure 4. Seasonal and inter-annual observation trends for tomtate and vermilion snapper.
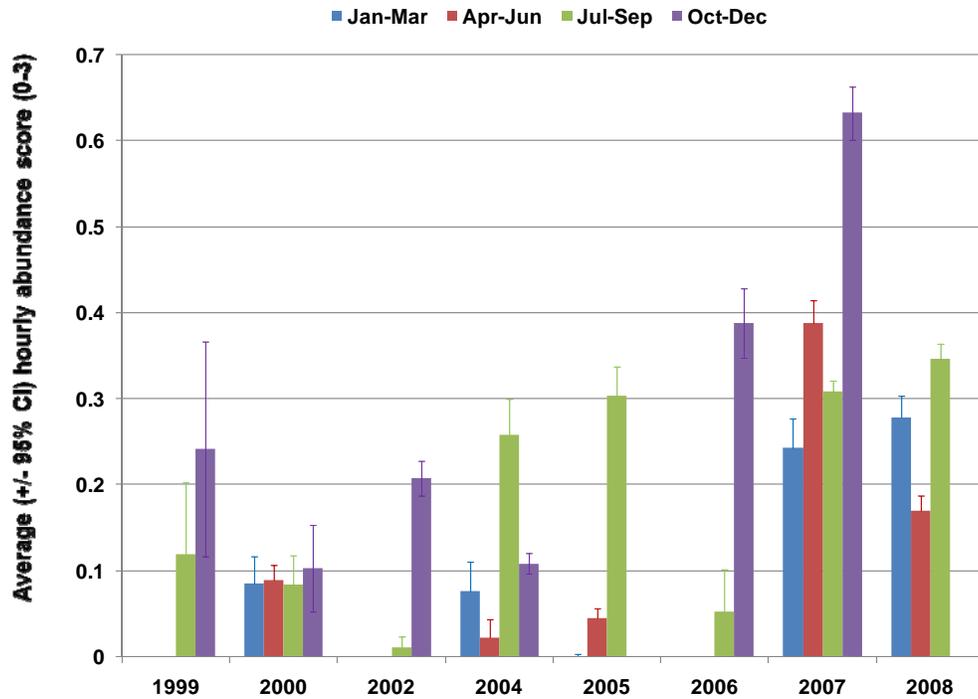
Figure 5. Seasonal and inter-annual observation trends for small forage and juvenile fishes.
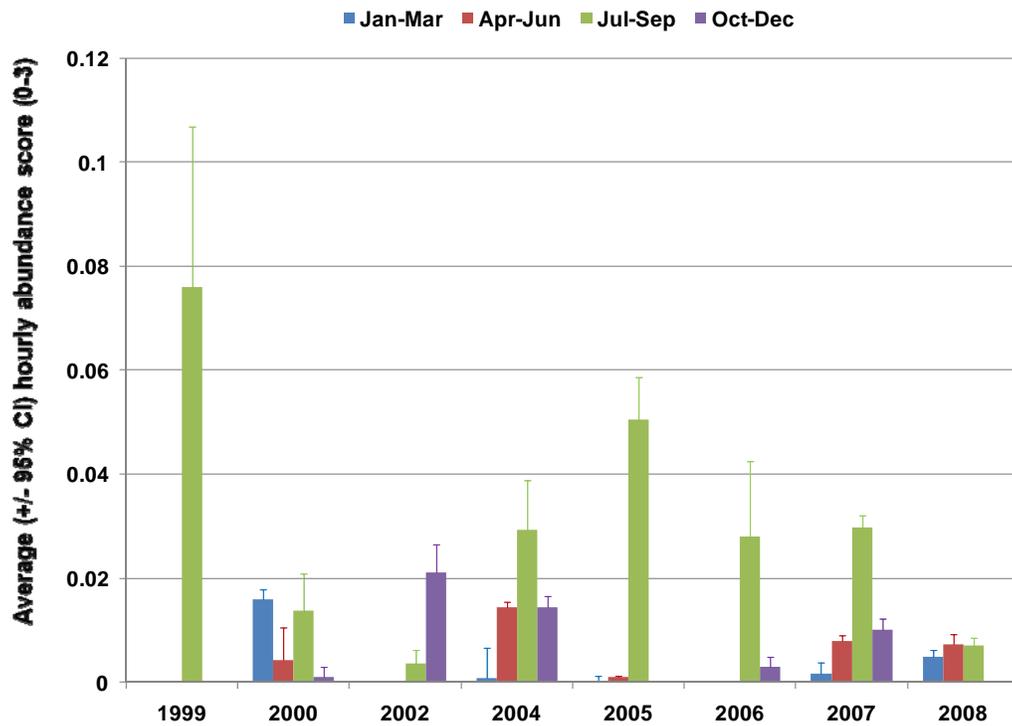
Figure 6. Seasonal and inter-annual observation trends for pelagic predators.

Results Part Three: Species Co-Occurrence and Environmental Associations.
Average monthly bottom water temperature (Figure 7) between Jan and Mar was consistently
between 57°F and 59°F in all years except for 2002 (60.3°F), 2007 (61.1°F) and 2008 (63.3°F).
Average monthly bottom water temperature between Jul and Sep was consistently between 78°F
and 81°F, except for 2002 when average monthly water temperatures were slightly warmer
(82.4°F). Spring (Apr to Jun) average monthly bottom water temperatures were warmer than fall
(Oct to Dec) temperatures during the same year between 2000 and 2002 (70°F to 72°F in spring
vs. 67°F to 69°F in fall), similar (<1°F difference) between spring and fall in 2004 and 2006, but
cooler than fall temperatures in 2005 (67.2 vs. 70.4°F). Inter-annual variation in seasonal ranges
in bottom water temperatures was minimal, despite influence of La Niña conditions (NWS 1) in
1999-2000 and 2007-2008 and El Niño conditions in 2002-2003, 2004-2005 and 2006 (NWS 2).

Average monthly bottom water salinity varied by just 1.8 parts (34.2 to 36.6 psu) among seasons
between 2000 and 2008 (Figure 7), and fluctuated erratically rather than with a seasonal pattern.
Greatest (1.8 parts) annual variation in average monthly salinity was observed in 2006 and the
least (0.3 parts, 3 seasons only) annual variation in 2008. Similar to bottom water temperature,
climatic forcing due to El Niño/La Niña conditions did not appear to correspond with changes in
salinity at the research site. Minor variability within seasons coupled with oscillating patterns
among seasons suggests that changes in salinity reflect wind mixing and freshwater inputs due to
precipitation or estuarine run-off (Atkinson et al., 1978; Bush, 1988) as well as inputs from high
salinity water masses like the Gulf Stream (Blanton et al., 1981; Matthews and Pashuk, 1986).
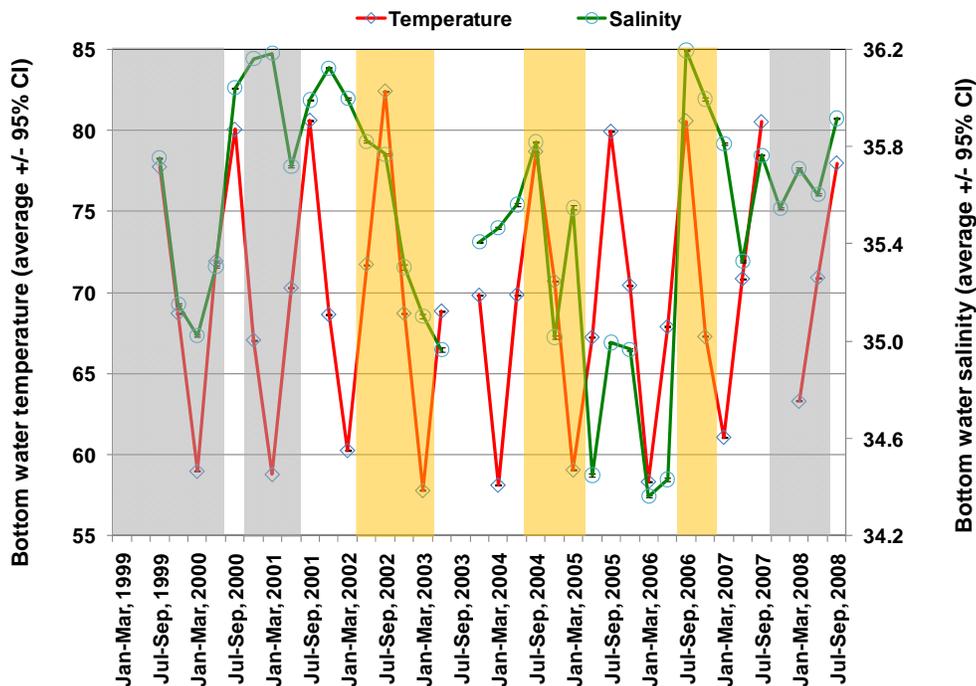
Figure 7. Average monthly (by season) bottom water temperature and salinity readings at the
research site between 2000 and 2008. Gray shaded periods indicate La Niña and orange shaded
periods indicate El Niño conditions; non-shaded periods indicate normal conditions.

Seasonal groupings of species and species groups (Figure 8) were also revealed by a Principal Components Analysis (PCA) which compared similarity and correspondence between daily abundance indices among species and species groups; however, the largest (first) component only accounted for 15% of the variance in this data set (Appendix 2). In other words, although there was substantial similarity in the seasons when these species or species groups were observed, differences in daily and inter-annual observations for a given species or species group were only weakly attributable to co-occurrence with the species or species groups examined.

PCA was also conducted using a sub-set of days (*n*=723) when corresponding data was also available for seven environmental metrics for which calculating average daily values made sense (i.e., all but time of day and three tidal metrics). The results from this PCA indicated increasing salinity and decreasing wave heights were associated with increasing abundance indices and vice versa (Figure 9). The first component for this analysis only accounted for 26% of the total variance (Appendix 3); thus, a substantial amount of the variation among daily average index scores remained unaccounted for. Performing the PCA based on day-hr observations (*n*=5,450) in order to include time of day and tidal metrics decreased the variance accounted for to 17% (Appendix 4) due to introducing many non-observation events. Using day-hrs instead of days also modified environmental associations, such that increasing water temperature (and declining photoperiod) had the greatest association with increased abundance indices (Figure 10).

Even if co-occurrence and environmental associations were completely independent, the maximum amount of variance accounted for by the first components of these PCA tests is 41%; thus, other factors exert great influence on inter- and intra-daily abundance score trends. One plausible factor is variability among species, and is detailed in the species profiles that follow.
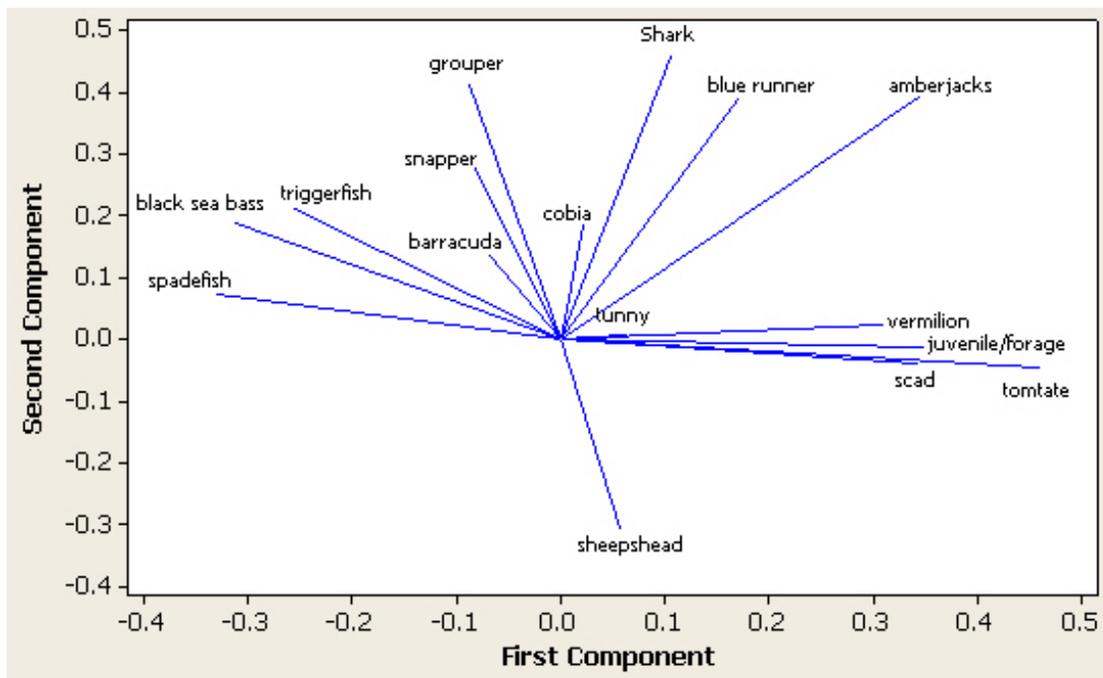
Figure 8. Co-occurrence of species and species groups based on daily abundance indices.
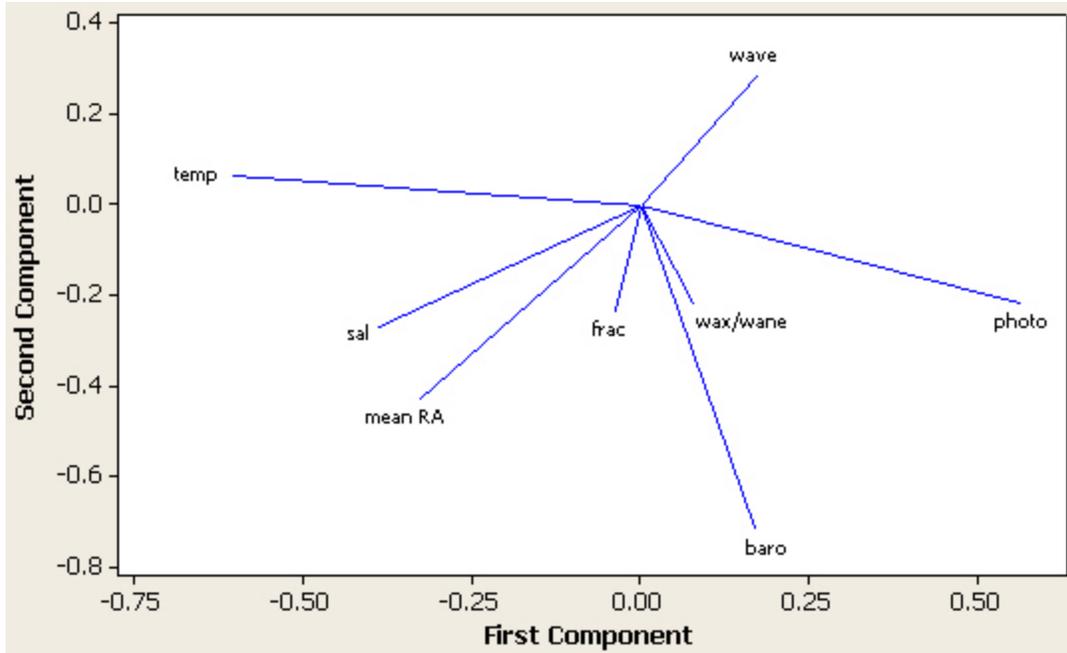
Figure 9. Associations between average daily abundance indices (16 species/groups) and seven environmental factors.
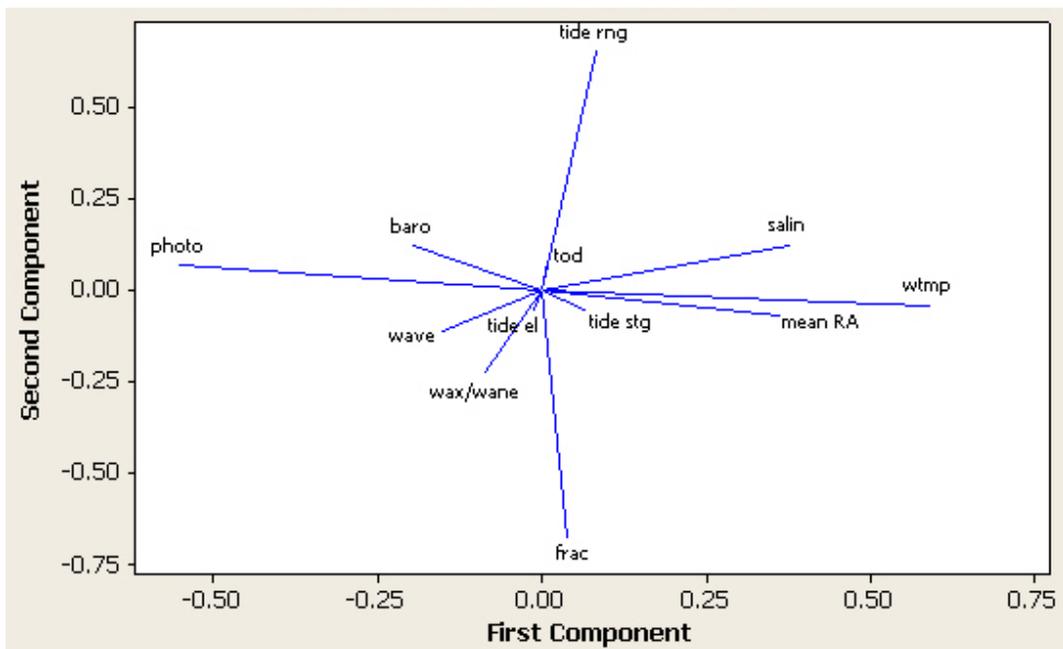
Figure 10. Associations between average day-hr abundance indices (16 species/groups) and 11 environmental factors.

11

Species Profile: Black sea bass (*Centropristis striata*)
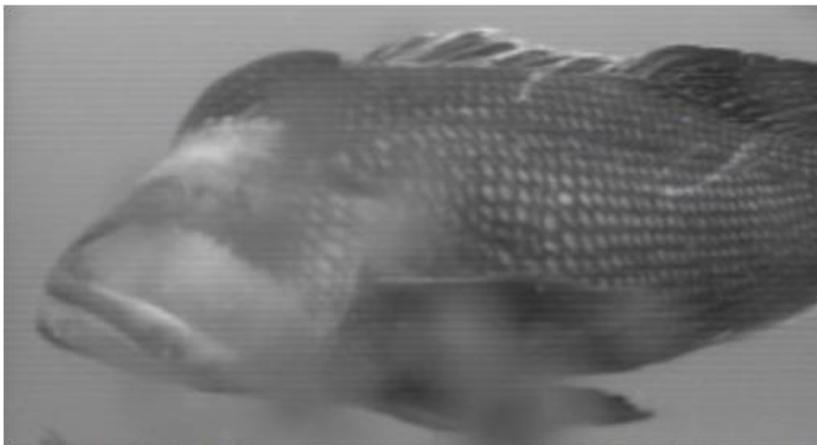
Male "gray-head" black sea bass close to camera, 4 April 2004 11:00 hrs

Black sea bass are distributed from Massachusetts through the South Atlantic Bight (SAB) and throughout the Gulf of Mexico (GOM), with three distinct populations or stocks recognized (1) north Cape Hatteras, NC; (2) south of Cape Hatteras; (3) and in the GOM (Steimle et al., 1999). Within the SAB, black sea bass comprise an important recreational and commercial fishery with fish typically growing to ~16.2" total length and ≥ 10 years old (McGovern et al., 2002); however, growth rates are known to vary spatially and temporally for this species. For example, black sea bass caught north of Cape Hatteras are generally larger and older than in the SAB (Steimle et al., 1999), larger/older fish also tend to be caught offshore vs. inshore within the SAB (Sedberry et al., 1998). In South Carolina, the sport fish record is 8 lbs, 3 oz.

Results from tag-and-release studies in the SAB (Sedberry et al., 1998) and acoustic telemetry studies north of Cape Hatteras (Fabrizio et al., 2005) indicate that black sea bass exhibit strong habitat fidelity, with only a small percentage (~8%) of fish reported to move away from tagging locations (Low and Waltz, 1991; Sedberry et al., 1998). Movements of black sea bass away from tagging locations have been attributed to courtship and mating and/or seasonal re-location to over-wintering areas (Fabrizio, et al, 2005). Black sea bass are reported to migrate seasonally from shallow northern waters to warm deep waters off Virginia (Musick and Mercer, 1977); however, pronounced seasonal movements have not been reported for this species in the SAB.

Abundance indices for black sea bass were significantly different (Appendix 1) among seasons, with similar (and greatest) abundance indices observed between Jan-Mar and Oct-Dec, followed by Apr-Jun and then Jul-Sep (Figure 11). In all years, peak annual occurrence of black sea bass at the research site coincided with peak (January to April, to a lesser extent September-October) spawning activity for this species based on histology (Wenner et al., 1986). Both adult male and female black sea bass were observed during our study. Black sea bass are protogynous hermaphrodites, with immature fish beginning life as females, with some females transforming into males later in life. However, the presence of males within a local group may reduce the frequency of females transforming into males (Benton and Berlinsky, 2006).

Significant inter-annual differences in abundance indices were noted in all seasons, with greatest indices occurring in 2004 and then 2002 or 2000 depending on the season. Abundance indices in summer and fall 2005-2008 were not statistically different from summer and fall 1999, when black sea bass were not observed. Black sea bass had one of the highest rates of identifications which were considered non-usable (Table 4); however, this loss was relatively stable throughout the study and did not affect abundance indices. Assuming that black sea bass were not removed from the site by fishing, reduced abundance indices post-2005 may reflect a greater need to forage away from the reef as competition for food increased. Black sea bass consume a variety of organisms associated with reefs and adjacent sand bottom (Sedberry 1988; Lindquist et al, 1994; Steimle and Figley, 1996), but a study at Gray's Reef found that their abundance bass was related to the percent cover of sessile invertebrates (Kendall et al., 2008).

The decline in abundance indices for black sea bass in this study occurred rapidly, even if the source of those changes was not immediately evident. The South Atlantic Fishery Management Council (SAFMC) currently manages black sea bass as part of the Snapper-Grouper Complex. Black sea bass are listed as over-fished, and a management plan (Amendment 13C) to promote their recovery was enacted in 2005. Indications of potential over-fishing include greater catch rates during the 1970's than during 2005-2006 (Rudershausen et al., 2008) as well as a decline in the size at maturity between the late 1970's and late 1990's (McGovern et al., 2002).

Eighty percent of black sea bass observations occurred under the following conditions: bottom water temperatures between 59.6°F and 77.7°F (average = 69°F); wave heights between 1.6' and 5.9' (average = 3.4'); barometric pressures between 1006.9 and 1021.3 mb (average = 1013.7 mb); and salinities between 34.8 and 36.1 psu (average = 35.4 psu). Significant differences were not detected between tidal metrics and abundance indices (Appendix 5) nor with respect to moon fraction or phase (Appendix 6); however, black sea bass were observed statistically less frequently between 16:00 and 18:00 hrs local time (Appendix 5).
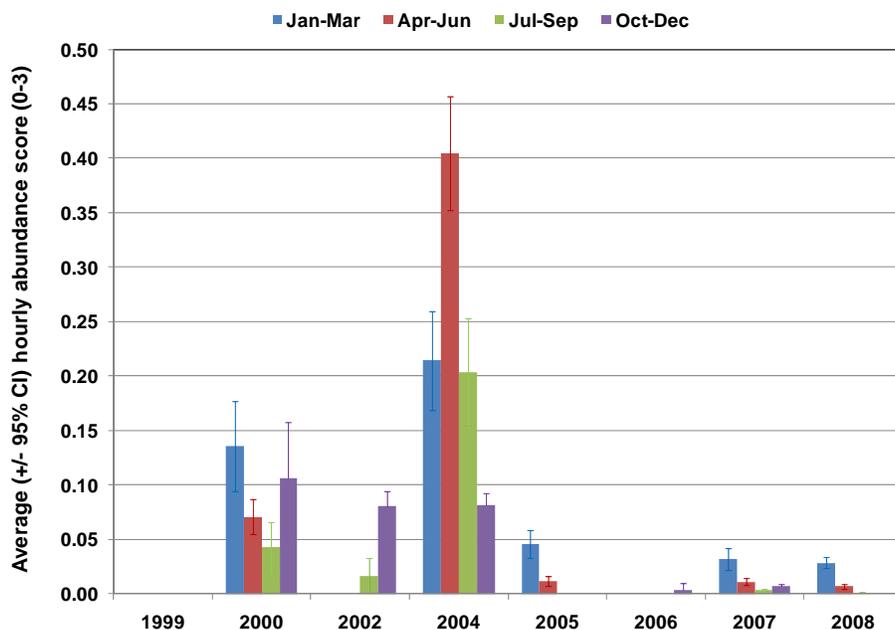
Figure 11. Seasonal and inter-annual abundance indices for black sea bass.

13

Species Profile: Gray triggerfish (*Balistes capriscus*)

Gray triggerfish close to camera, 23 June 2004 12:00 hrs

The gray triggerfish is a moderately large, benthic reef fish adapted to slow movements and nipping hard shelled invertebrates off and near reef structures (Durie and Turingan, 2001). Predation is minimized due to a tough skin and large dorsal spine that is only retracted when the following small spine is "triggered". In the Atlantic Ocean, gray triggerfish range extends from Nova Scotia in North America to Argentina in South America (Murdy et al., 1997). Gray triggerfish commonly occur at hard bottom habitats (Sedberry and Van Dolah, 1984), along ridges and rocky outcrops (Gledhill, 2005) and in association with offshore oil rigs to depths of 200' (Stanley and Wilson, 2003). In the SAB, gray triggerfish reach sizes up to 22" fork length and live to be upwards to 10 years old (Moore, 2001); similar sizes but slightly older age estimates (13 years) are reported from the GOM (Johnson and Saloman, 1984). Male gray triggerfish tend to be larger than similar-aged females and both sexes tend to be larger offshore (Moore, 1001). Male and female gray triggerfish tend to occur in equal numbers wherever they are found (Moore, 2001). The South Carolina sport fish record is 13 lbs, 9 oz.

Seasonal distribution data for gray triggerfish in the SAB are considerably less available relative to other species, although it has generally been assumed from a few tag-recapture data sets (Appendix 7) that adult gray triggerfish exhibit resident tendencies. During the first year of life, however, gray triggerfish occupy pelagic habitats (Dooley, 1972) which may include floating mats of *Sargassum* as nursery habitat (Wells and Rooker, 2004). In the GOM, gray triggerfish exhibit high site fidelity on both artificial and natural reefs (Ingram and Patterson, 2001); however, some seasonal movements do occur (Stanley and Wilson, 2003).

Abundance indices for gray triggerfish were significantly different (Appendix 1, Figure 12) among seasons, with greatest abundance indices in Oct-Dec followed by Apr-Jun, with no significant differences noted between Jan-Mar and Jul-Sep; however, a high degree of variance (as evidenced by large 95% confidence intervals) was associated with many average abundance indices for a given season. In the SAB, gray triggerfish spawn offshore (generally in depths <150') during June and July (Moore, 2001). Because adult males defend benthic egg nests (Mackichan and Szedlmayer, 2006), territorial behavior could increase abundance indices if nests were located within view of the cameras; such behavior may have contributed to increased abundance indices in Apr-Jun 2004 relative to other years.

Significant inter-annual differences in abundance indices were noted in all seasons, with greatest abundance indices occurring in 2004, followed by 2002 and then 2000. Abundance indices in 2007 and 2008 were similar and along with data collected for 1999 represented the lowest abundance indices in all seasons. Abundance indices during 2005-2006 also generally ranked in the lower half of scores, except for summer 2006. Similar to black sea bass, and likewise assuming that gray triggerfish were not involuntarily removed from the research site by fishing activities, reduced observation between 2005 and 2008 may reflect greater need to forage away from the reef concurrent with reduced food availability. Although foraging for gray triggerfish primarily involves picking food from structures, their diet is diverse. Kauppert (2002) noted that the nearly 1/5th of the diet of gray triggerfish included fish in addition to benthic crabs, shrimps and barnacles which comprised >50% of stomach contents. In the GOM, gray triggerfish also forage on sand dollars up to 100' away from reefs (Kurz, 1995).

The South Atlantic Fishery Management Council (SAFMC) currently manages gray triggerfish as part of the Snapper-Grouper Complex. Between 1983 and 1996, when catch rates for many reef species were in decline, catch rates for gray triggerfish actually increased at sites sampled between 85' and 180' (McGovern et al., 1998a).

Eighty percent of gray triggerfish observations occurred under the following conditions: bottom water temperatures between 61.0°F and 78.8°F (average = 71.1°F); wave heights between 1.6' and 5.6' (average = 3.4'); barometric pressures between 1006.2 and 1021.0 mb (average = 1013.4 mb); and salinities between 34.7 and 36.1 psu (average = 35.4 psu). Significant differences were not noted between abundance indices and tidal metrics or time-of-day (Appendix 5), nor with respect to moon phase or fraction of the moon illuminated (Appendix 6).
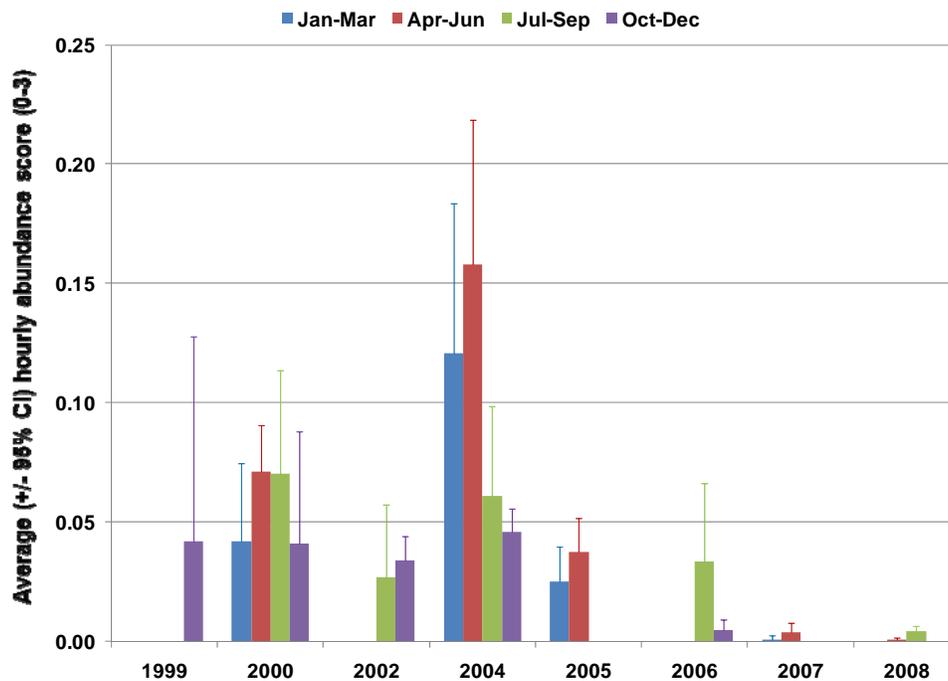
Figure 12. Seasonal and annual abundance indices for gray triggerfish.

Species Profile: Atlantic spadefish (*Chaetodipterus faber*)

School of spadefish at the research reef, 25 May 2008 10:00 hrs

Atlantic spadefish are a mid-sized reef fish that is seasonally abundant in the Atlantic Ocean between Massachusetts and southeastern Brazil as well as in the GOM (Robbins et al., 1986). Atlantic spadefish generally occur in large schools, making them one of the most abundant fishes at habitats where they are found. In the SAB, Atlantic spadefish are reported from artificial reefs and high-relief live-bottom areas of near-shore and mid-shelf waters (Hayse, 1989) and from shallow water (<75') oil and gas platforms in the GOM (Stanley and Wilson, 2003); however, despite an affinity for high profile platforms, fish aggregation devices (FADs) do not appear to be especially beneficial for attracting Atlantic spadefish (Rountree, 1990). In the SAB, Atlantic spadefish may attain an age of 8 years and 20" total length (Hayse, 1989). The South Carolina sport fish record for Atlantic spadefish is 14 lbs, 2 oz.

Recapture data for Atlantic spadefish in the SAB are incredibly sparse, despite tag and release of more than 1,000 fish (Appendix 7); thus, seasonal distribution patterns for this species in the SAB have largely been inferred from seasonal catch data. In contrast, 3,204 spadefish were tagged by recreational anglers in the VA Game Fish Tagging Program (VGFTP) between 1995-2002, resulting in 319 recapture events (Lucy and Bain, 2003). Most spadefish recaptured in the VGFTP are within-season (May-August) recaptures at the same site where tagged, and it is not uncommon for fish to be recaptured at the same site almost to the day in a subsequent year.

Abundance indices for Atlantic spadefish were significantly different (Appendix 1) among seasons, with indices progressively decreasing throughout the calendar year (Figure 13). Seasonal catch data suggests that Atlantic spadefish are distributed between estuaries and near shore waters (<65' deep) between May and November before moving further offshore (91-184') for the winter (Hayse, 1989; Schwartz, 1998). Seasonal abundance indices for Atlantic spadefish at the research site seem to support the presumption of seasonal movements, at least for fish less than two years old. Considerably less is known about the winter whereabouts of Atlantic spadefish older than two years (Hayse, 1989). Distinction was not made between adult and juvenile spadefish in video data files, but large and presumably adult fish were seen at least occasionally. Thus, it is possible that older fish may have over-wintered at the research site.

Significant inter-annual differences in abundance indices were noted in all seasons; however, in contrast to black sea bass and gray triggerfish inter-annual trends were inconsistent. Winter abundance indices were highest and similar in 2004, 2005 and 2007, with no significant differences between the first (2000) and last (2008) winters of this study. As such, and given seasonal catch data (Hayse, 1989) for this species, lower winter scores in 2000 and 2008 likely represent Atlantic spadefish over-wintering elsewhere. Given that spawning occurs closer to shore between May and August (Chapman, 1978; Hayse, 1989), food availability may determine the duration that Atlantic spadefish remain at the research site. Gallaway et al. (1979) found associations between Atlantic spadefish associated with oil platforms in the GOM and the amount of plankton and suspended particulate matter in the water column; indeed, Atlantic spadefish were occasionally observed feeding on Ctenophores at the research site. In contrast, Kauppert (2002) reported that Atlantic spadefish consumed bryozoans, hydroids and benthic crabs and shrimp at artificial reef units off South Carolina. Nonetheless, low abundance indices (with little seasonal variability) for Atlantic spadefish in 2008 were peculiar.

Eighty percent of Atlantic spadefish observations occurred under the following conditions: bottom water temperatures between 58.4°F and 80.0°F (average = 71.1°F); wave heights between 1.6' and 6.1' (average = 3.4'); barometric pressures between 1007.2 and 1022.2 mb (average = 1014.6 mb); and salinities between 34.9 and 36.1 psu (average = 35.5 psu). Significant differences (Appendix 5) were noted between abundance indices and tide stage (slightly greater on flood tides) and tide range (greatest at extremes); however, significant differences were not noted with respect to time-of-day, moon phase or fraction of the moon illuminated (Appendix 6).
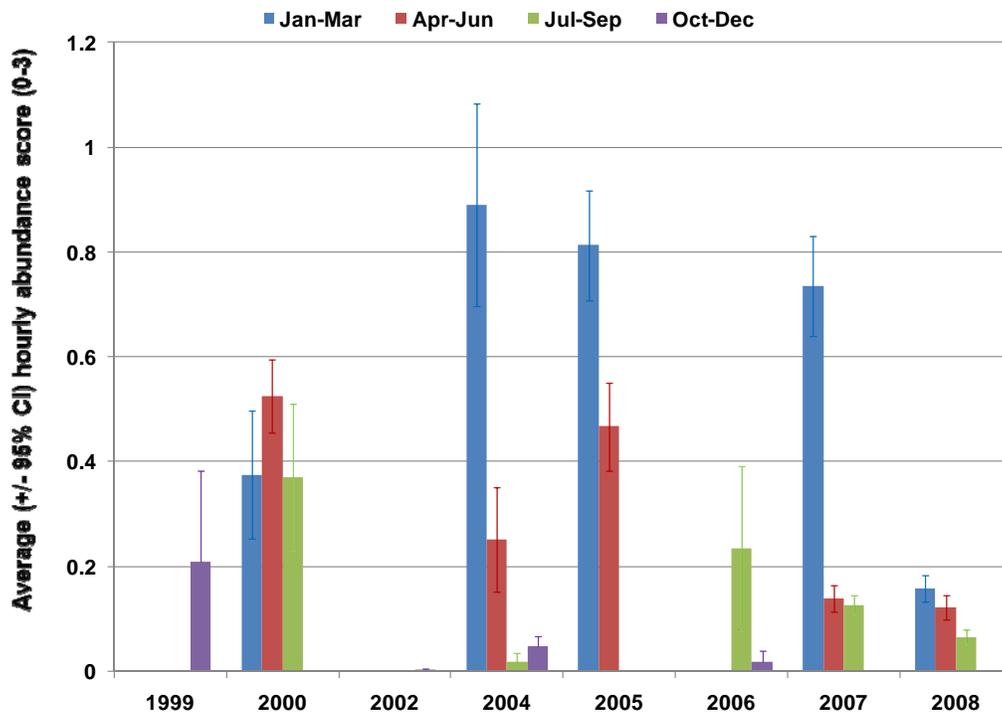
Figure 13. Seasonal and annual abundance indices for Atlantic spadefish.

Species Profile: Sheepshead (*Archosargus probatocephalus*)

A nice sheepshead approaches a modestly fouled camera, 6 March 2008 12:00 hrs

Sheepshead are distributed from Nova Scotia to the eastern tip of South America as well as throughout the Gulf of Mexico and Caribbean Sea; however, they are notably absent from Bermuda, the West Indies and Grenada (Robbins et al., 1986). Historically, sheepshead were abundant between Chesapeake Bay and New York; however, they are now considered rare in the northern part of the range (Wenner and Archambualt, 2006). The appearance of sheepshead is distinct, and is one of three local fish with black vertical bars on each side of the body; however, Robbins et al. (1986) report that populations in the western GOM have only five bars (one less than in the SAB) and that bars are narrower for sheepshead collected from Central and South America. Sheepshead live to be more than 20 years old in SC; growth is relatively rapid during the first five years (to about 18" fork length), but tapers off considerably afterwards (Wenner and Achambault, 2006). The South Carolina sport fish record for sheepshead is 15lbs, 12 oz.

Seasonal inshore-offshore movements are suspected from catch data; however, because 90% of sheepshead landed in SC are predominantly (84%) caught inshore (Wenner and Archambualt, 2006), tag-recapture data documenting inshore-offshore movements are hard to come by. Among SC recreational anglers, presumably fishing inshore, only 99 of 1028 sheepshead tagged between 1974-1992 were recaptured (Davy, 1994). Only 33 of 642 sheepshead tagged in the VGFTP between 2001-2006 were recaptured, with some movement noted between Chesapeake Bay and Cape Hatteras (Lucy and Bain, 2007). Low (32 of 1117 fish) recapture rates are also noted for inshore FL waters, despite use of a variety of sampling gears and a localized sampling (Tremain et al., 2004). Low recapture rates throughout the geographic distribution range suggest tag-recapture methods may not be suitable for studying this species.

Sheepshead were first observed at the research reef occurred in mid-November 2002 (one video), but were not seen again until late November 2007. Between November 2007 and June 2008, sheepshead (1-2 fish per video) were seen sporadically, but in every month with usable data. Sheepshead were also observed once in September 2008, the last month of the study. Given the sustained (albeit infrequent) observation of sheepshead during the last year of the study, it appears that at least a pair of sheepshead may have become established at the small research site eight years after it was constructed.

Species Profile: Snappers
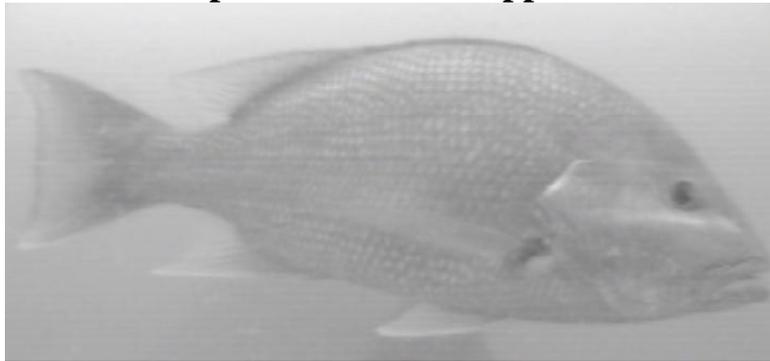
A red snapper swims near the cameras, 30 September 2002 08:00 hrs

Snappers (Family Lutjanidae) are widely distributed in the Western Atlantic Ocean. Most snappers are found between Brazil and the GOM, with distribution along the U.S. Eastern Seaboard to at least NC and often Massachusetts (Robbins et al., 1986). A notable exception is the American red snapper, which is replaced by the Caribbean red snapper south of the Yucatan Penninsula (Robbins et al., 1986). Red snapper are probably the most prized reef fish species in the SAB, although they are far more common in the GOM (Manooch and Potts, 1997). Red snapper attain a maximum size of 38" total length and ages of 45 years; however, growth rates slow considerably slower after the first 10 years (White and Palmer, 2004). The SC sport fish record for red snapper is 37 lbs, 8 oz and has not been broken since 1964. Excluding vermilion snapper (which is discussed elsewhere in this report), SC sport fish records have been established for Cubera Snapper (118 lbs, 0 oz), Mutton Snapper (26 lbs, 0 oz), Gray Snapper (11 lbs, 1 oz) and Yellowtail snapper (10 lbs, 8 oz).

Due to incredibly similar appearances among snapper species particularly in black and white video clips, fish could not be identified to the species level with a high degree of certainty; thus, analyses were performed for fish identified to the genus level (*Lutjanus*) instead. It is believed that three species (red snapper, gray snapper, cubera snapper) were observed; however, fish that resembled gray snapper were only seen between January and June 2005 and fish that resembled cubera snapper were only seen between October and December 2007. Fish resembling red snapper were also seen during both of those periods as well as other times of the year.

Abundance indices for snappers were very low (Figure 14), but were significantly (Appendix 1) greater during Oct-Dec and Apr-Jun than other times of the year. Peak spawning for red snapper occurs between June and September in the SAB (White and Palmer, 2004), but abundance indices during Jul-Sep were among the lowest. In both the GOM (Wade, 1978) and SAB (Parker, 1990), red snapper occupying shallow, near-shore reefs are reported to move to deeper water at temperatures below 61°F; however, in our study abundance indices were lowest during the coldest months. Infrequent observation of snappers at the research site during seasons when they would've been expected to occur suggests that either they utilized the small research reef infrequently and/or daily behavior patterns precluded more frequent observation. For example, both hatchery-raised and wild juvenile red snapper occur inside of structures during the day and occur outside of structures at night (Masuda et al., 2003); thus, juvenile snapper were unlikely to be seen by cameras. Adult red snapper are also reported to consume pelagic zooplankton during the day (McCawley et al, 2006); thus, they may have fed above the cameras during daylight.

Inter-annual differences in abundance indices were noted in all seasons, but primarily consisted of one or two years with higher scores but without consistent trends. Overall low frequency of observation was inconsistent with red snapper residence patterns reported from numerous studies in the GOM. Red snapper occurring in waters 60-90' deep appear to move less than 4 nm to adjacent reefs even during winter (Wade, 1978). Tag-recapture and acoustic telemetry data demonstrate strong site fidelity, with 67% of fish remaining within 1/8th of a mile from where released for more than 1.6 years (Szedlmayer, 1997; Szedlmayer and Schroepfer, 2005; Schhoepfer, 2006). Long-distance movements may be hurricane-induced (Ingram and Patterson, 2001; Watterson, et al, 1998), with movements up to 190 nm reported within the GOM (Patterson, et al, 2001) and 80 nm off the east coast of FL (Moe et al, 1970).

A SEDAR (Southeast Data Assessment and Review) stock assessment for red snapper concluded over-fishing (at eight times the sustainable level) has occurred since the 1970's. In response, the SAFMC proposed an interim closure for this fishery in federal waters (Amendment 17). Despite infrequent observation in this study, consistent detection across years suggests that a network of remote video stations would provide a highly advantageous data set for future stock assessments for snappers in the SAB, particularly if used in combination with acoustic telemetry monitoring which has provided considerable insight into red snapper residence patterns in the GOM.

Eighty percent of snapper observations occurred under the following conditions: bottom water temperatures between 61.7°F and 78.1°F (average = 70.6°F); wave heights between 1.5' and 6.0' (average = 3.4'); barometric pressures between 1005.9 and 1020.2 mb (average = 1012.9 mb); and salinities between 34.5 and 36.0 psu (average = 35.2 psu). Significant (Appendix 5) differences were noted between abundance indices percent of tide elapsed (greatest between 50.1% and 75%); however, significant differences were not noted with respect to tide stage, tide range, time-of-day, moon phase or fraction of the moon illuminated (Appendices 5 and 6).
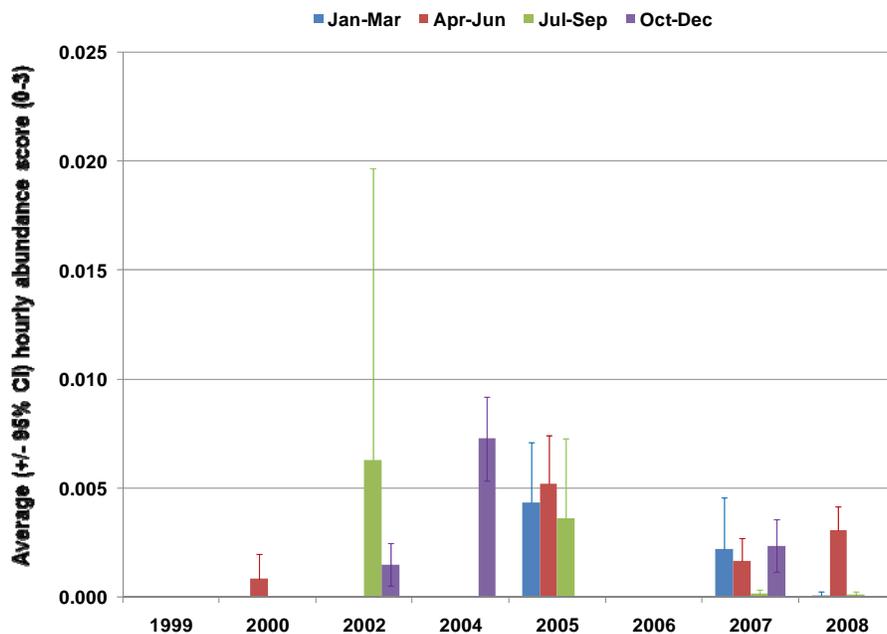
Figure 14. Seasonal and annual abundance trends for snappers.

Species Profile: Groupers

A charcoal belly male gag (female below) at the research site, 29 March 2007 10:00 hrs

Groupers are distributed throughout the SAB and GOM, with some species ranging as far south as Brazil and as far north as Massachusetts (Robbins et al., 1986). Groupers can live to at least 26-30 years and all groupers are protogynous hermaphrodites, such that some females later become males (Harris and Collins, 2000; Harris et al., 2002). Spawning occurs in large aggregations and grouper are known to rapidly travel long-distances for the sole purpose of spawning (Gilmore and Jones, 1992; Koenig et al., 1996; McGovern et al., 1998a). For many grouper species, drastic reduction in the percentage of large males in populations is attributed to fishing pressure on annual spawning grounds (Coleman et al., 1996; McGovern et al., 1998b; Harris et al., 2002). Maximum size for gag grouper (50" total length) is larger than scamp (35" fork length), two common groupers in the SAB. The SCDNR recognizes seven records for groupers, with gag and scamp grouper records set at 48 lbs, 8 oz and 25 lbs, 9 oz, respectively.

Substantial tagging data exist for gag in the SAB (McGovern et al., 2005); however, considerably less data are available for scamp (Appendix 7). In the SAB, McGovern et al. 2005) reported that the largest gag were generally caught in waters deeper than 115', which also coincided with a water depth range (65-131') where frequency of movement away from the tagging site was greatest; gag tagged deeper than 131' appeared to be resident. Of the nearly 100 gag that moved more than 100 nm away from the release site, most were tagged off SC and moved to GA, FL or into the GOM. Mean length and depth of capture for tagged gag suggested that fish were predominantly targeted during the spawning season (February-April). Gag in spawning condition are historically collected off the Carolinas (Manooch and Haimovici, 1979).

Due to incredibly similar appearances among grouper species (i.e., yellowmouth vs. scamp grouper and gag vs. black grouper) and the ability to rapidly change their color patterns and appearance (Gilmore and Jones, 1992), fish could not be identified to the species level with a high degree of certainty; thus, analyses were performed for fish identified to the genus level (*Mycteroperca*) instead. More than 90% of groupers seen between Jan-Jun 2007 were able to be identified as gag (48-70% between Jul-Dec 2007) and a red grouper (*Epinephelus morio*) was also observed in December 2007. In all other seasons and years, ≥80% of observations were only reliably identified to genus. Among 387 video data files when a "best guess" was rendered, 64% of identifications listed as *Mycteroperca* sp. exhibited the scamp/yellowmouth grouper appearance and were observed with similar frequencies throughout the study.

Seasonal abundance indices were greatest in Oct-Dec, least in Apr-Jun, and not different between Jan-Mar and Jul-Sep (Appendix 1, Figure 15). Inter-annual variation was significant within seasons, but inconsistent among seasons. In 2007, "charcoal belly males" were seen, quite remarkable given that male gag represent <5% of populations (Coleman et al., 1996; McGovern et al., 1998b). The research site was located in the general vicinity where SC-tagged gag have been recaptured following long-distance movements presumably for spawning (McGovern et al., 2005); thus, the presence of males in the spring and year-round occurrence of gag in 2007 suggests spawning may have occurred at the research site. Courtship (Gilmore and Jones, 1992) may also have been noted, but not fully captured with 10-second video files.

Low abundance indices for grouper relative to other reef fish species seen at the research site may be related to habitat quality. At the Grays Reef National Marine Sanctuary also off GA, scamp and gag grouper were only observed at 11% of surveyed ledges, and their presence was strongly related to the height of ledge undercut (Kendall, et al. 2008). Gag are also known to select habitats for shelter over potential growth and feeding benefits (Lindberg et al., 2006). Scamp feed primarily on fish, including large numbers of round scad (Kauppert, 2002) as well as tomtate and vermilion snapper (Matheson et al., 1986), whereas gag consume primarily fish (at least occasionally including black sea bass) and squid (Kauppert, 2002).

Eighty percent of grouper observations occurred under the following conditions: bottom water temperatures between 60.6°F and 81.4°F (average = 71.1°F); wave heights between 1.6' and 6.3' (average = 3.6'); barometric pressures between 1007.6 and 1020.3 mb (average = 1013.6 mb); and salinities between 34.8 and 36.0 psu (average = 35.5 psu). Abundance indices for groupers were significantly greater (Appendix 5) between 07:00 and 09:00 hrs (and least between 16:00 and 18:00 hrs) as well as on waxing moon phases (Appendix 6); however, significant differences were not noted with respect to tidal metrics.
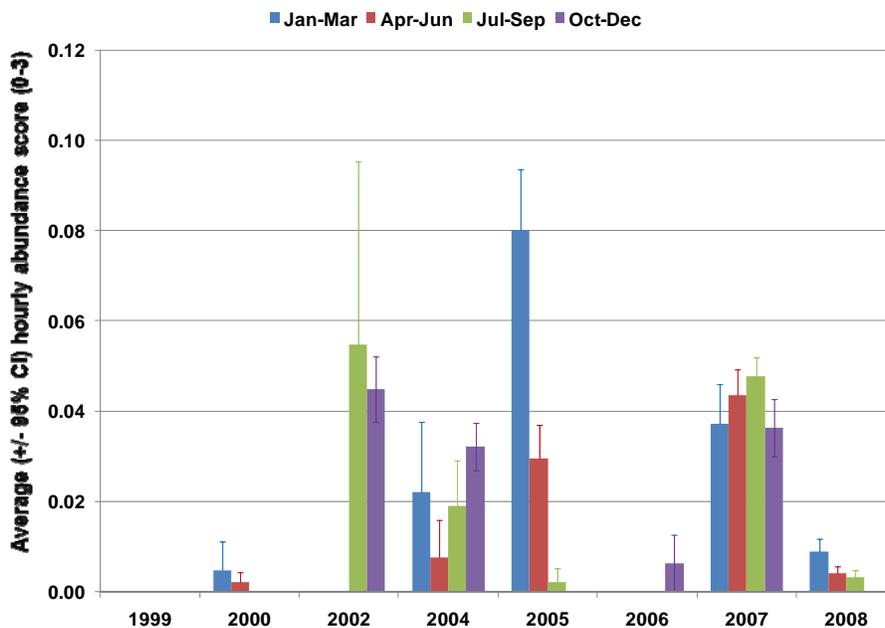
Figure 15. Seasonal and annual abundance trends for groupers.

Species Profile: Tomate (*Haemulon aurolineatum*)
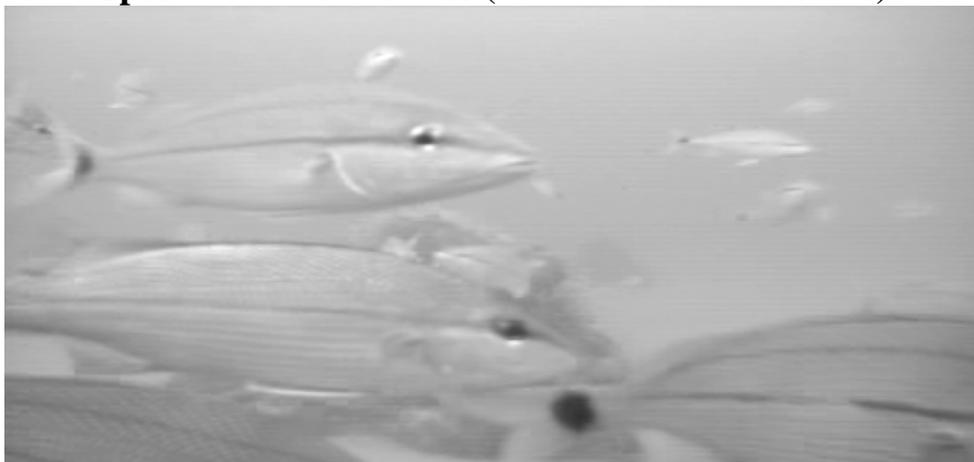
School of tomate aggregating at the research site, 30 November 2007 10:00 hrs

Tomtate are small members of the grunt family (Haemulidae) distributed from Massachusetts, throughout the SAB and GOM, and south to Brazil (Robbins et al., 1986). In the SAB, tomtate may attain an age of 17 years and reach a maximum size of 10.3" fork length, but older fish may often be shorter than younger fish suggesting that growth slows after 9-10 years and roughly 8" fork length (Mikell et al., in prep.). Sex ratios are slightly male-biased (1.6 to 1 ratio) and peak spawning occurs between April and June (Mikell et al., in prep.). Tomtate are abundant in trawl catches over low relief, "live bottom" habitats (Manooch and Barans, 1982), but densest concentrations occur at high-relief, shelf-edge habitats (Schobernd and Sedberry, 2009). Although small in size, tomtate have become an important recreational/head-boat species in the SAB due to the relative scarcity of and/or the presence of catch limits on most large species of the snapper/ grouper complex. A state record tomtate has not officially been declared in SC.

Given their small size and perception of tomtate as a forage or bait species, the lack of published tag-recapture data is not surprising. Indeed, of the >42,000 fish (representing 96 species) tagged by recreational anglers in the SC Marine Game Fish tagging program between 1974 and 1992, not one was a tomate (Davy, 1994). Seasonal distribution patterns for this species must therefore be pieced together from catch data. Within the SAB, massive schools of juvenile tomtate occur over reefs each spring. Adult tomtate are abundant in trap catches at mid-latitudes (30.5-33.0°N) and at mid-depths (62-180'); however, larger fish are more abundant further south (29.5-30.0°N) and in deeper (183-213') waters (Mikell et al., in prep.). Seasonal movement between offshore habitats in the winter and inshore habitats during periods of warm water is suggested from commercial trawl catches in the Caribbean off Mexico (Sauskan and Olaechea, 1974).

Seasonal abundance indices were significantly different (Appendix 1) for tomate, with greatest observation in Jul-Sep, similar overall observation levels in Jan-Mar and Oct-Dec, and lowest observation levels in Apr-Jun (Figure 16). Inability to distinguish abundance indices between Jan-Mar and Oct-Dec was biased by very strong Jan-Mar scores in 2007 and 2008 as well as lack of data collection for Oct-Dec in 2008. Tomtate were not seen in data deemed suitable for analyses in either Jan-Mar or Apr-Jun in both 2004 and 2005 (and in only six video data files not deemed suitable for analyses); thus, strong Jan-Mar and Apr-Jun scores for 2007 and 2008 are noteworthy, and suggest greater annual utilization of the research site by tomtate over time.

Significant inter-annual differences were noted, with highest abundance indices in all seasons recorded in 2007 and 2008. Abundance indices between Jan-Jun were greater in 2008 than in 2007, coinciding with a decline in groupers that eat tomtate (Mattheson et al., 1986). Similar to other adult grunts, adult tomtate aggregate near reef structures during the day and feed over adjacent sand bottom at night (Ogden and Eharlich, 1977; see review in Darcy, 1983); thus, a decline in known predators should have increased the day-time shelter value of the research site. Because polychaete worms (Sedberry, 1985; Kauppert, 2002) constitute important prey items for tomtate but not other species, less competition for these prey items was likely very beneficial for tomtate as the abundance of fish increased at the reef with time.

As part of the snapper-grouper management group, the same gear restrictions that apply to other species also apply to tomtate; however, except for the requirement that fish be landed with their heads and fins intact, no other regulations (i.e., size or catch) currently exist. Between 1983 and 1996, trap catches of tomtate increased at depths of 85-115' within the SAB, coincident with the decline of known predators. However, like their predators before them, the affinity of tomtate to aggregate (particularly during the day) could eventually render them susceptible to over-fishing. Even selected removal of tomtate may adversely affect the overall health of the reef, given that by foraging away from reefs tomtate provide an important pathway for nutrient and energy flow for the reef (Ogden and Eharlich, 1977; see review in Darcy, 1983).

Eighty percent of tomtate observations occurred under the following conditions: bottom water temperatures between 64.2°F and 81.5°F (average = 75.0°F); wave heights between 1.6' and 6.1' (average = 3.4'); barometric pressures between 1008.4 and 1021.6 mb (average = 1013.6 mb); and salinities between 35.2 and 36.1 psu (average = 35.7 psu). Abundance indices for tomtate were greatest between 10:00-12:00 and 16:00-18:00 and on flood tides when 50.1-75% of the water level change had transpired (Appendix 5); however, no significant differences were noted between abundance indices and moon fraction or phase (Appendix 6).
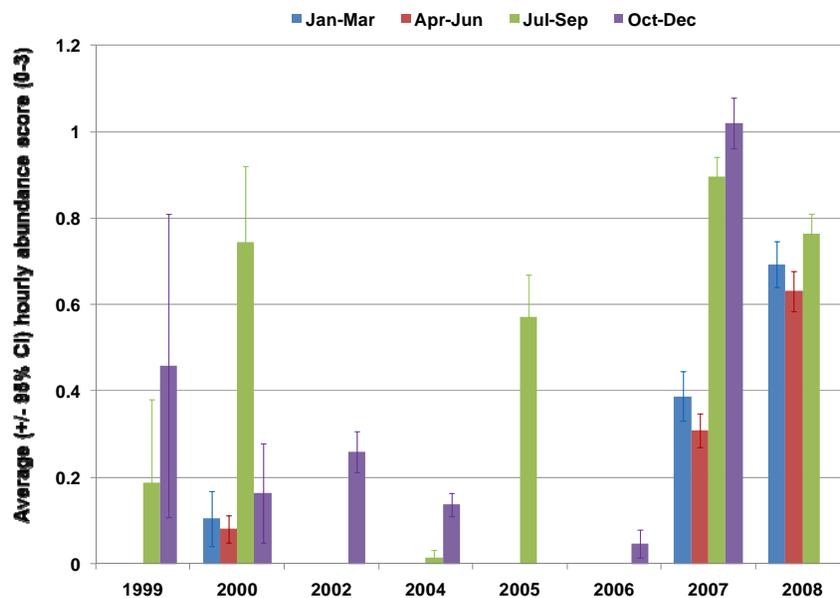
Figure 16. Seasonal and annual abundance trends for tomtate.

Species Profile: Vermilion snapper (*Rhomboplites aurorubens*)

A large vermilion snapper mixed with tomtate, 28 August 2008 12:00 hrs

Vermilion snapper (also known as mingo snapper or beeline snapper) occur in schools near reef structure throughout the SAB and GOM to Brazil (Robbins et al., 1986). Populations from the western and eastern GOM are genetically distinct (Tringali and Higham, 2007), suggesting a relatively little movement within the GOM. Vermilion snapper have been aged to 13 years and 19.7" fork length in the SAB (Mikell et al., 2007) and to 14 years and 23.6" total length in the GOM (Potts et al, 1998). Size at age in the GOM is reported to vary with reef site, depth zone and distance from shore (Allman, 2007). In the SAB, the spawning season runs from April through September (Cuellar et al., 1996) with a peak in July (Mikell et al., in prep.). Female vermilion snapper tend to be larger than males at a given age and are caught nearly three times as often as males (Mikell, et al., 2007). The South Carolina sport fish record is 6 lbs, 10 oz.

Only eight vermilion snapper were tagged by recreational anglers in the SC Marine Game Fish tagging program between 1974 and 1992 (Davy, 1994), which is not surprising given their small size and perception as a forage or bait species. A tagging study by Fable (1980) suggested high site fidelity given that 92% of recaptures (*n*=39) occurred where vermilion snapper were tagged between 30 and 847 days earlier. In the SAB, vermilion snapper have been caught using traps fished in waters 69-300'deep; however, greatest catch rates occurred in water 69-131' deep and between 30-32°N (Mikell et al., 2007). Peak catches in the fall (during late afternoon and evening) are also reported for hook-and-line fishing at shelf-edge habitats located in waters 210-600' deep (Grimes et al., 1982). Vermilion snapper may leave near-shore and mid-shelf reefs at bottom water temperatures <61°F (Parker, 1990).

Seasonal abundance indices were significantly different (Appendix 1, Figure 17) for vermilion snapper, with greatest abundance indices during Jul-Sep coinciding with peak spawning indices for females (Mikell et al., 2007). Low abundance indices during Jul-Sep 1999 and 2006 may be attributed to limited data available for analyses (*n*=31 to 32 day-hrs). Infrequent observation during Jul-Sep in 2000 and 2004 (when five times as many sampling opportunities were available compared to 1999 and 2006) is puzzling. Furthermore, low abundance indices during Jul-Sep 2000 and 2004 were not attributed to large amounts of data being excluded due to poor visibility and/or fouling (i.e., vermilion snapper appeared in only 25 to 29 video data files collected during those sampling periods independent of visibility and fouling).

Inter-annual differences in abundance indices were significant, with greatest indices during the last three years of the study. Similar to tomtate, increased observation of vermilion snapper in later years corresponds to reduced abundance indices for larger reef fish that prey upon vermilion snapper (Mattheson et al., 1986). With respect to improved foraging opportunities for vermilion snapper over time, their diet is dominated by planktonic organisms that were not monitored during the video survey such as demersal zooplankton (assumed to be eaten during nocturnal emergence), large decapods, fishes and cephalopods (Sedberry and Cuellar, 1993). Like tomtate, vermilion snapper represent an important pathway for transporting energy and nutrients; however, whereas tomtate provide a horizontal pathway between the reef and the adjacent sand, vermilion snapper provide an important linkage between the reef and the ocean surface (Sedberry and Cuellar, 1993).

Vermilion snapper are managed by the SAFMC in the multi-species snapper-grouper group; however, unlike tomtate for which only gear restrictions apply, a 12" total length minimum size limit has been in place for vermilion snapper since October 2006. A recreational bag limit of five fish per person per day is also in effect (along with commercial harvest restrictions), and no recreational harvest is permitted between November and March.

Eighty percent of vermilion snapper observations occurred under the following conditions: bottom water temperatures between 69.3°F and 81.7°F (average = 76.8°F); wave heights between 1.6' and 5.7' (average = 3.2'); barometric pressures between 1008.7 and 1019.7 mb (average = 1014.0 mb); and salinities between 35.1 and 36.1 psu (average = 35.7 psu). Abundance indices were greatest on flood tides and when the difference between high and low water was between 5.2 and 6.6' (Appendix 5); however, no significant differences were noted with respect to time of day, percent of tide elapsed or moon fraction/phase (Appendices 5,6).
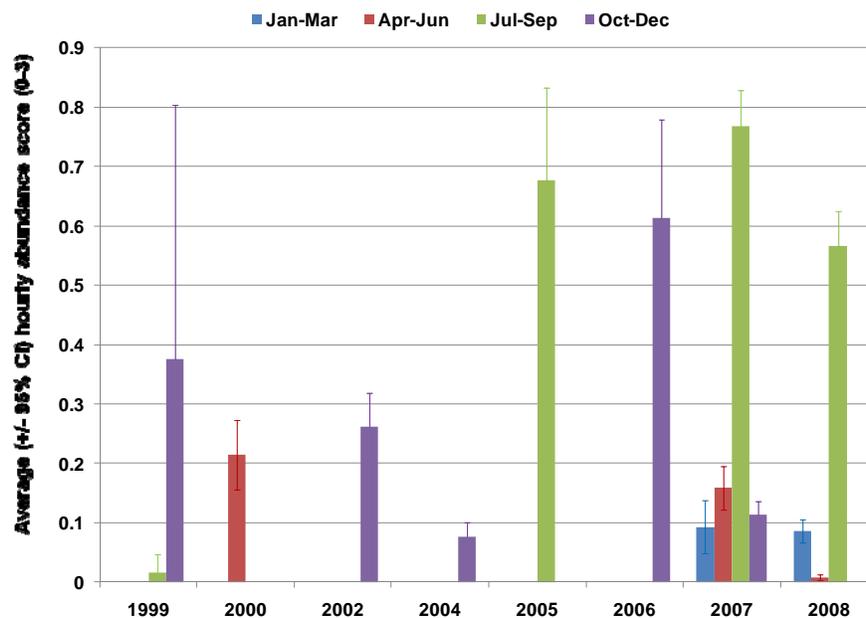
Figure 17. Seasonal and annual abundance trends for vermilion snapper.

Species Profile: Mixed forage, juveniles and scad

Scad and mixed forage/juveniles swarm the site, 31October 2002 08:30 hrs

Given the level of difficulty of identifying some large fishes with a high degree of certainty, it is not surprising that confident identification of mixed-species groups of small fishes was also problematic. Because these small fishes often occurred in very large numbers best described as "swarms", it was important to document their occurrence at the reef given their potential importance as prey. At times these small fishes appeared to represent juvenile reef fishes, notably vermilion snapper and tomtate; however, because small juveniles and traditional 'bait' species (scad, herring, anchovies, sardines, etc.) were integrated, they were collectively treated as "mixed forage/juveniles". However, this category was reserved for when identification to genus or species level (using body shape and swimming behavior as clues) was not possible.

Ninety-nine percent of observations of 'bait' species that could be identified were classified as scad (aka, cigar minnows) and were comprised of round scad (*Decapterus punctatus*) and bigeye scad (*Selar crumenopthalmus*), although other scad species may also have been present. Round herring (*Etrumeus teres*) and Spanish sardines (*Sardinella aurita*) comprised the bulk of non-scad 'bait' identifications, though at least one anchovy species and unidentified herrings/shad were also identified infrequently. Non-scad species may have been present more frequently than 1% of the time; however, given that scad were identifiable in over 10,000 videos it is not very likely that non-scad 'bait' species were prevalent at the site.

Seasonal and annual occurrence for mixed forage/juveniles (Figure 18) and scad (Figure 19) were statistically different (Appendix 1). For both groups, abundance indices were greatest in Jul-Sep, followed by Oct-Dec; however, abundance indices for mixed forage/juveniles were greater in Apr-Jun than Jan-Mar, but vice-versa for scad. Abundance indices for both groups were also greatest in 2007-2008. High mixed forage/juveniles abundance indices in Jan-Mar 2004 may partially explain low indices for vermilion snapper (Figure 17); however, alternative identification (i.e, mixed vs. vermilion) was not implicated for Jan-Mar 2005. Scad were also not observed in Jan-Mar 2004 or 2005, but were present in Jan-Mar 2000, 2006 and 2007.

Eighty percent of mixed forage/juvenile observations occurred under the following conditions: bottom water temperatures between 64.4°F and 81.4°F (average = 74.4°F); wave heights between 1.5' and 5.5' (average = 3.2'); barometric pressures between 1008.1 and 1020.6 mb

(average = 1014.0 mb); and salinities between 35.2 and 36.1 psu (average = 35.6 psu). Eighty percent of scad observations occurred under the following conditions: bottom water temperatures between 64.3°F and 81.4°F (average = 74.3°F); wave heights between 1.6' and 6.4' (average = 3.5'); barometric pressures between 1008.5 and 1022.0 mb (average = 1014.7 mb); and salinities between 35.2 and 36.1 psu (average = 35.7 psu). Abundance indices were significantly greater for mixed forage/juveniles between 10:00 and 12:00 hrs, but scad abundance indices were significantly lower between 07:00 and 09:00 hrs (Appendix 5). Abundance indices for both groups were significantly greater on flood tide stages and when water level change ranged from 3.6' to 6.6' (mixed forage/juveniles only), but indices for either group were not affected by the percent of tide change elapsed nor moon phase or fraction illuminated (Appendices 5,6).
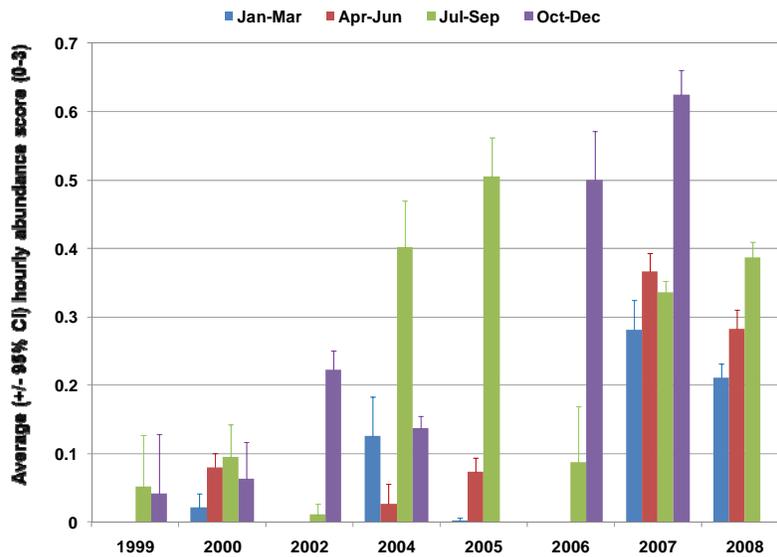
Figure 18. Seasonal and annual abundance trends for mixed forage/juveniles.
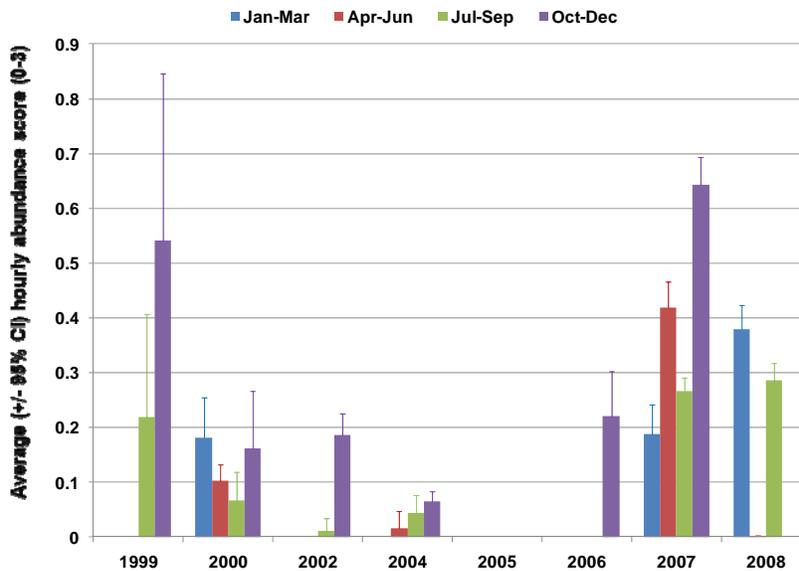
Figure 19. Seasonal and annual abundance trends for scad.

Species Profile: Blue runner (*Caranx crysos*)

School of blue runner raiding the research site, 23 October 2002 12:00 hrs

Blue runner are often found in schools in proximity to reef habitats and other structures. They occur on both sides of the Atlantic Ocean and range from Nova Scotia to Brazil in the Western Atlantic (de Andrade, 2007). Blue runner are an important commercial species in Brazil, where they are often used as bait (de Andrade, 2007). Small blue runner are used as live-bait in the U.S., but a directed fishery does not exist. In the GOM, blue runner live to be at least 11 years and reach lengths of 28" (Berry, 1974). Growth is fast, with 75% of maximum size achieved prior to year three (Goodwin and Johnson, 1986). Similar to other jacks, young-of-the-year and juvenile blue runner are found near fish aggregation devices (FADs) and in association with *Sargassum* mats (Wells and Rooker, 2004; Campo et al., 2007). A state game fish record for blue runner is not currently recognized by the SCDNR.

Blue runner are infrequently (if ever; Davy, 1994) tagged and released by recreational anglers. A commercial fishery does not exist and scientific investigations are rare in the SAB; thus, other than documenting that they occur at FADs (Rountree, 1990), very little is known about their distributional patterns in the SAB. In the GOM, blue runner are one of the three most abundant fish species seen at oil platforms ranging in depth from 72' to >700' (Stanley and Wilson, 2003). Spawning peaks between June and August, with a second peak in October (Goodwin and Finucane, 1985). Sex ratios vary greatly among sampling locations within the GOM, with nearly equal sex ratios in the western GOM but female-biased ratios in the eastern GOM (Goodwin and Finucane, 1985). In the GOM, spawning occurs in frontal zones (Ditty et al., 2004).

Abundance indices for blue runner (Figure 20) were statistically different (Appendix 1) among seasons and among years within seasons. High mean abundance indices in Jul-Sep 1999 were associated with large confidence intervals due to a small sample size (*n*=32 day-hrs), as well as limited sampling coincident with the approach and subsequent passage of a major hurricane (Floyd) close enough to the site that it shifted the reef units and disrupted camera orientations. Similarly, frequent observation of blue runner during Oct-Dec only occurred during 2002, which also coincided with a climatic 'anomaly' (i.e., the onset of heavy precipitation (onshore) that was sufficient to reverse a five-year drought by the following spring (SCDNR, 2003)).

When observed, blue runner nearly always occurred in large schools that appeared to raid the reef in search of prey, the latter of which often moved close to the cameras and reef units during such events. In addition to consuming small fish, Keenan et al. (2003) also found that adult blue runner near oil platforms consumed planktonic decapods, chaetognaths, amphipods, and other invertebrates all within the upper range of sizes present in their plankton samples. Near manned oil platforms in the GOM, artificial light may contribute to the continuous feeding of blue runner during both day and night periods (Benfield, et al., 2005).

Blue runner were more temporally-restricted than any other species seen at the research site; although seen as early as 6 March (2008) and as late as 20 November (2002), 80% of blue runner observations occurred between 22 July and 17 September. Among years, 80% of blue runner observations occurred under the following conditions: bottom water temperatures between 77.0°F and 82.0°F (average = 80.0°F); wave heights between 1.6' and 5.1' (average = 3.0'); barometric pressures between 1008.6 and 1016.5 mb (average = 1012.6 mb); and salinities between 35.2 and 36.1 psu (average = 35.7 psu). Abundance indices for blue runner were greatest when 50.1-75% of the tide stage had elapsed and when water level differences between high and low water was less than 6.6 ft (Appendix 5); however, no significant differences were noted with respect to time of day, tide stage, or moon fraction or phase (Appendices 5,6).
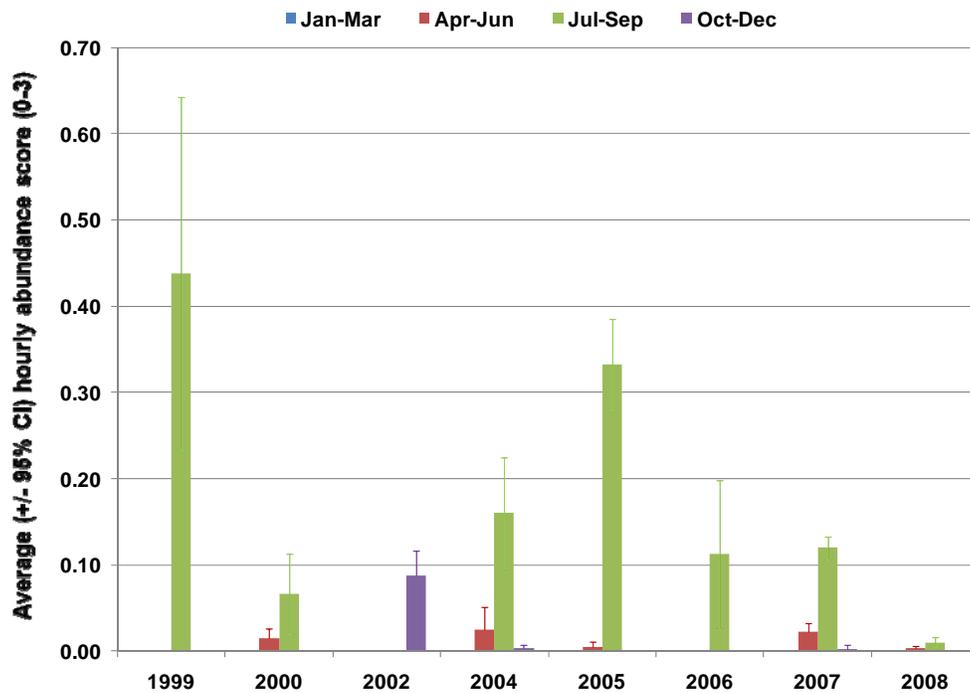
Figure 20. Seasonal and annual abundance trends for blue runner.

Species Profile: Amerjacks (*Seriola* sp.)

A pair of amberjack navigate through a swarm of juveniles and scad, 12 July 2007 12:00 hrs

Amberjacks are often found in relatively large schools near reef structure. Amberjacks are distributed worldwide (Robbins et al., 1986). Four species of amberjack (Greater amberjack, Lesser amberjack, Almaco jack and banded rudderfish) in the genus *Seriola* look remarkably similar and are common in the SAB; thus, for the purposes of this report we analyzed the data at the genus level to increase the certainty of proper identification.

Greater amberjack found in the SAB are genetically distinct from greater amberjack found in the GOM (Gold and Richardson, 1998). Tag-recapture studies also confirm a very low (<2%) rate of mixing of fish between the SAB and GOM (Davy, 1994; McClellan and Cummings, 1997). In the GOM, young (39-150 days old) amberjack associate with floating *Sargassum* mats, and abundance and growth rates are reported to be greatest offshore (15-70 nm vs. <15 nm; Wells and Rooker, 2004). Greater amberjack in the SAB attain lengths of 57" total length and ages of 13 years (Harris et al, 2007) with slightly older (15 years) fish reported from the GOM (Thompson et al, 1999). Amberjack caught near artificial reefs at depths of 230-312'off SE FL were larger than at similar habitats in shallower (≤66') water (Byran, et al, 2006), suggesting an increase in size of amberjack with water depth. Sex ratios are slightly female-biased and females tend to be larger than males of the same age (Harris et al., 2007). Despite the occurrence of several species off SC, there is only a single SC record (99 lbs, 11 oz) for "amberjack."

Tagging data off SC provides insight into the capability for long-distance movements as well as inter-annual affinity for locations off SC. Among 537 amberjack tagged between 1975 and 1992 35 (6.5%) were recaptured (Davy, 1994). Nearly two-thirds of fish were tagged off SC in the fall, many of which were recaptured off S FL in Apr-Jun, where amberjack are thought to spawn (Harris et al, 2007). An amberjack tagged off Savannah, GA was recaptured 6.3 nm from where released almost three years earlier (Davy, 1994). In the GOM, 90% of amberjack are recaptured within 16 nm of tagging locations; however, long-distance movements associated with spawning migrations have also been noted (Thompson et al., 1999; Ingram and Patterson, 2001).

Seasonal abundance indices were greatest (Appendix 1) in Jul-Sep, similar between Apr-Jun and Oct-Dec and least in Jan-Mar (Figure 21). Amberjack were consistently seen between May and Dec; however, in 2008 they remained through Jan and were seen four times during Feb-Mar before regular sightings resumed in May. Abundance indices remained low throughout the study, but were comparable to scores for grouper and snapper, which also peaked in 2007. Similar to snapper and grouper, the diet of amberjack is composed primarily (80%) of fish, but also includes squid, octopus and shrimp (Manooch and Haimorici, 1985; Kauppert, 2002). Thus, competition for resources and/or pursuit of generally mobile prey may have contributed greatly to low frequency of observation of amberjack at the research site. However, consistent observation over a large portion of the year (May to Dec) suggests that the resources available to amberjacks at this small research reef were reasonably abundant.

Eighty percent of amberjack observations occurred under the following conditions: bottom water temperatures between 72.9°F and 81.7°F (average = 77.9°F); wave heights between 1.6' and 5.3' (average = 3.0'); barometric pressures between 1008.9 and 1018.7 mb (average = 1013.5 mb); and salinities between 35.3 and 36.1 psu (average = 35.7 psu). Abundance indices were greatest when 0-50% of the tide stage had elapsed and on flooding tides; however, size of tide range was not a significant factor (Appendix 5). Abundance indices for amberjack were also significantly greater between 07:00-09:00 hrs (Appendix 5). Under laboratory conditions, juvenile greater amberjack feed for 1-3 hrs following the onset of light (Chen et al, 2007); thus, our data suggests that diel foraging strategies may persist in adults as well. No significant differences were noted between abundance indices and moon fraction or phase (Appendix 6).
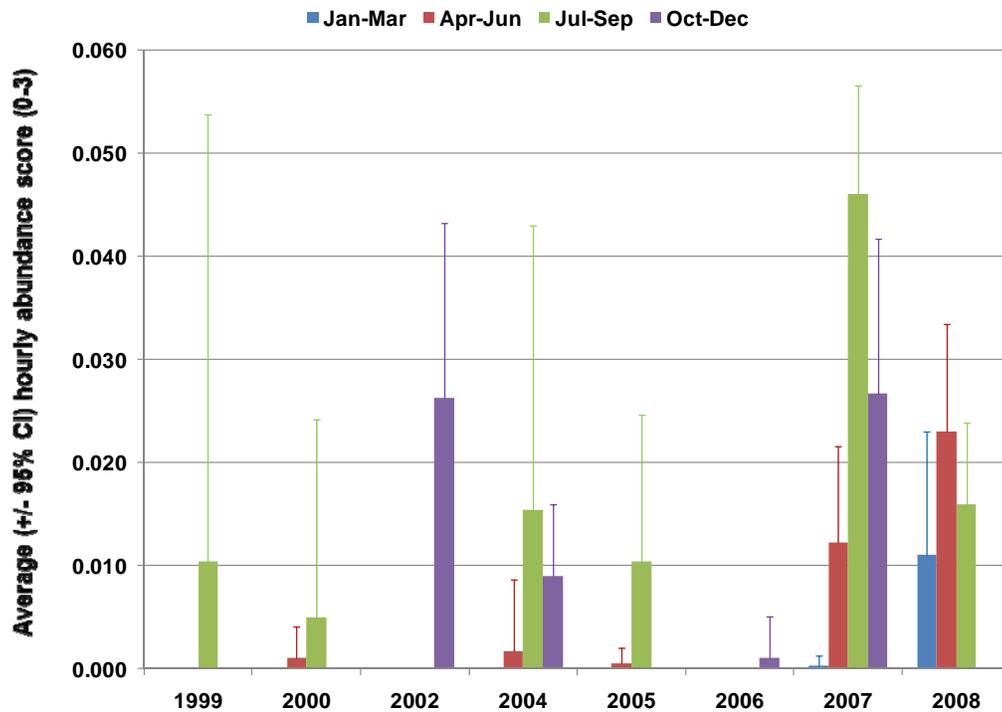
Figure 21. Seasonal and annual abundance trends for amberjacks.

Species Profile: Great barracuda (*Sphyraena barracuda*)

A solitary Great barracuda patrols the research site, 11 September 2006 15:00 hrs

The great barracuda has a world-wide distribution and is commonly associated with reefs in the SAB and throughout the Caribbean (Robbins et al., 1986). Similar to some sharks and whales, individual barracuda can be identified by differences in natural markings (Wilson et al., 2006). Peak spawning occurs in July but spans between May and Sep (de Sylva, 1963). Seagrass beds and mangroves provide nursery habitats for juveniles (<11" total length) throughout the year, but juvenile barracuda also occupy near-shore reefs during the dry summer season (Dorenbosch et al., 2004; Faunce and Serafy, 2008). Adult barracuda occur much further from shore than juveniles, as evidence by seasonal abundance at oil and gas platforms in the GOM at depths ranging from 200-720' (Stanley and Wilson, 2003). Great barracuda grow to >49" fork length (39 lbs) and 14 years of age; however, barracuda as large as 106 lbs and unknown age have been reported (de Sylva, 1963). The South Carolina sport fish record is 65 lbs, 0 oz.

Between 1974 and 1992, recreational anglers tagged 671 Great barracuda off SC, of which 26 (3.9%) were later recaptured (Davy, 1994). Six fish recaptured off eastern FL in fall and winter had been tagged off SC in August of the same year. A 24" barracuda tagged off Charleston in August and recaptured in Bimini nearly three years later holds the distinction of being the first tagged fish in this tagging program to ever be recaptured outside of the U.S. (Davy, 1994). Tag returns from 30 barracuda tagged in FL suggest that only large fish (23-44" total length) move long distances (up to 120 nm; Springer and McErlean, 1961). Direct visual observations of similar-sized barracuda (>27") in the GOM indicate that during non-migratory periods barracuda may remain within 0.1 nm of specific reefs for up to 318 days (Wilson et al., 2006).

Seasonal abundance indices were significantly (Appendix 1, Figure 22) greater in Oct-Dec than Jul-Sep, followed by Apr-Jun and then Jan-Mar. Persistence of barracuda through the fall documents that not all barracuda return to FL in Sep (de Sylva, 1963). Given recapture trends for barracuda tagged off SC in Aug, persistence of barracuda off GA until mid-Dec also suggests that when barracuda return to S FL, those movements occur rapidly. Sightings of barracuda in Feb 2008 may suggest that not all barracuda return to FL. In the FL Keys, adult barracuda are reported to aggregate in deep channels during the winter (de Sylva, 1963); thus, some barracuda may over-winter at similar depths and channels offshore rather than return all the way to FL.

Inter-annual variability in barracuda abundance indices were largely attributed to observation trends in two distinct periods. In Apr-Jun 2004, high abundance indices were associated with relatively few analyzable data points (n=95 day-hrs) which were four to six times less than during Apr-Jun in other years. Because a high degree of variability was noted in Apr-Jun 2004, abundance indices during this period may be artificially elevated due to data availability. Conversely, elevated abundance indices for Oct-Dec 2004 were not a reflection of data availability, which suggests that conditions may have been more favorable for barracuda at the research site during Oct-Dec 2004 than during Oct-Dec in other years. Abundance indices for many reef fishes were also high during Oct-Dec 2004, which may have created greater foraging opportunities given that both juvenile and adult barracuda eat small fish found in schools as well as solitary individuals near reefs (Schmidt, 1989; Nagelkerken and Velde, 2004). Indeed, on one occasion remote video sampling recorded what appeared to be a rapid consumption of a white-spotted soapfish (*Rypticus maculatus*) by a barracuda hovering directly in front of a camera.

Eighty percent of barracuda observations occurred under the following conditions: bottom water temperatures between 69.4°F and 81.5°F (average = 76.0°F); wave heights between 1.6' and 6.2' (average = 3.5'); barometric pressures between 1006.8 and 1018.8 mb (average = 1012.8 mb); and salinities between 35.1 and 36.1 psu (average = 35.6 psu). Abundance indices were significantly greater on flooding tides; however, size of tide range, percent of tide stage elapsed and time of day were not significant factors (Appendix 5). Significant differences were also not noted between abundance indices and moon fraction or phase (Appendix 6).
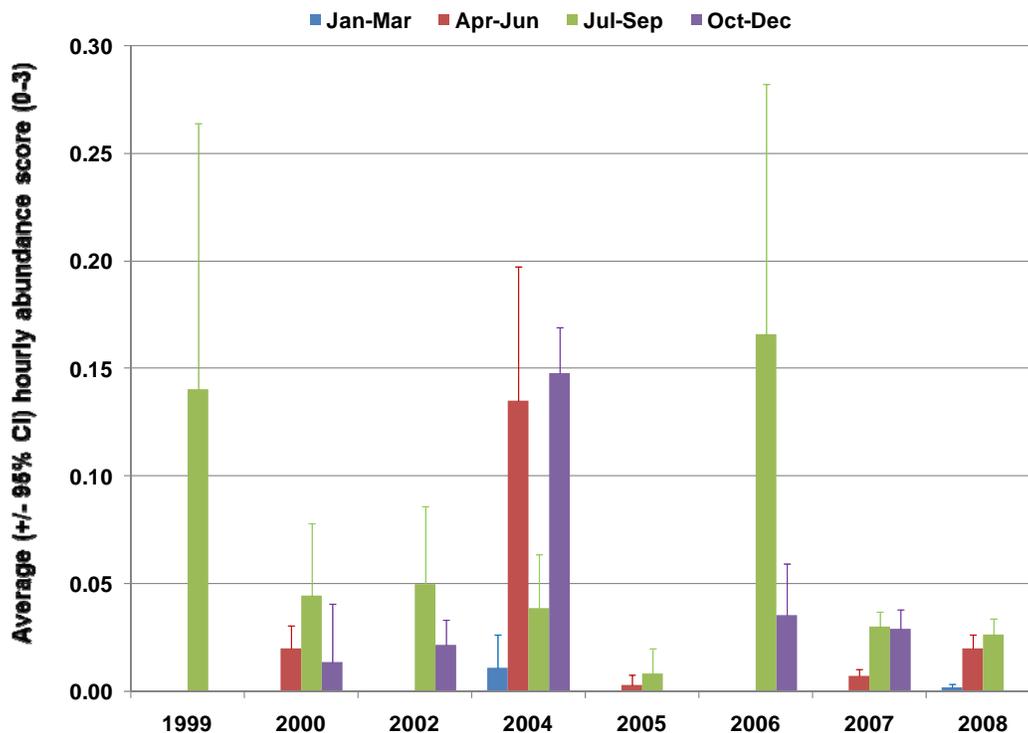
Figure 22. Seasonal and annual abundance trends for Great barracuda.

Species Profile: Little tunny (*Euthynnus alletteratus*)

A school of little tunny raiding the research site, 29 November 2007 15:00 hrs

Little tunny are distributed throughout the Western Atlantic Ocean (New England to Brazil), Eastern Atlantic Ocean and the Mediterranean Sea (Carpenter, 2002). In the SAB and GOM, little tunny occur over live-bottom and pelagic habitats (Parker et al., 1994) as well as at structures (Wickman et al., 1973) that attract small fish and invertebrates (which comprise little tunny diets; Manooch et al., 1985) at mid-water depths and at the sea surface. Spawning occurs in May in the Caribbean (Hare et al., 2001), and spawning can be so prolific that whale sharks continuously feed on recently spawned eggs at the surface (Hoffmayer et al., 2007). Little tunny live up to 9 years in the Mediterranean Sea with a typical size of 39" fork length (Kahraman and Oray, 2001). The South Carolina sport fish record is 29 lbs, 7 oz.

More than 90% of published studies involving little tunny are from the Eastern Atlantic, Mediterranean Sea and Adriatic Sea, with most of those studies pertaining to measuring mercury in tissue samples (as it relates to human consumption) and characterizing commercial landings; thus, tag-recapture data is severely limited for little tunny throughout its range. Between 1974 and 1992, recreational anglers in SC tagged 148 little tunny of which just one was recaptured; this fish traveled at least 420 nm between Charleston, SC and near Miami, FL during 74 days at large (Davy, 1994). Off GA and FL, adult little tunny are the most abundant non-shark species collected in the shark gill net fishery (Trent et al., 1997). Off Mexico, seasonal migration of little tunny is also suggested by commercial catch data (Cabrera, et al., 2005).

Little tunny were observed in 59 of 976 days (6%), with annual occurrences ranging from 0% (1999) to 9% (2007-2008) of days analyzed. Little tunny were only observed during one hour per day on 35 days (59%), but in four to 12 hours per day on 9 days (12%). Fifty-six percent of observations occurred in Jan-Mar and 36% in Oct-Dec. Eighty percent of observations occurred at bottom water temperatures between 60.0°F and 71.1°F (average = 63.8°F); wave heights between 2.4' and 6.5' (average = 4.4'); barometric pressures between 1009.0 and 1026.2 mb (average = 1018.4 mb); and salinities between 34.8 and 35.8 psu (average = 35.2 psu). Abundance indices were significantly greater after 12:00 hrs (Appendix 5) and when the moon was <25% illuminated (Appendix 6). In artisanal fisheries in Venezuela, catches of little tunny were positively correlated with wind velocity, but also negatively correlated with precipitation, air temperature and solar insolation (light and heat; Gonzalez et al., 2008).

Species Profile: Cobia (*Rachycentron canadum*)

A cobia cruises between a hovering grouper and the camera housing, 9 July 2007 17:00 hrs

Cobia are found in tropical and sub-tropical seas throughout the world except for the central and eastern Pacific Ocean (Shaffer and Nakamura, 1989). Female cobia tend to be larger than male cobia at a given age, and female cobia reach larger maximum sizes (65" vs. 56" fork length) in the GOM than off the U.S. East Coast (Franks and Brown-Peterson, 2002). Both sexes reach maximum sizes at older ages off the U.S. East Coast than in the GOM (14 yrs vs. 9 yrs for males; 13 yrs vs.11 yrs for females), suggesting faster growth in the GOM. Differences in growth rates may be related to differences in diet, with fish representing a large component of the diet of cobia in the GOM (Franks et al., 1996; Meyer and Franks, 1996) compared to a prevalence of crabs and other invertebrates in NC (Smith, 1995) and Chesapeake Bay (Arendt et al., 2001). The Chesapeake Bay is historically important for spawning (Joeseph et al., 1964) and the same cobia return in subsequent years (Lucy and Bain, 2002). Nearly 85% of fishing effort for cobia in SC occurs in Port Royal Sound (PRS) during the spring spawning run, where site high fidelity is also high (Davy, 1994; Hammond, 2001). After leaving PRS in July, the distribution of cobia is poorly documented, though at least some cobia over-winter in FL (Hammond, 2001). The state record for cobia (92 lbs, 10 oz) was set off Hilton Head Island in 2009.

Cobia were observed in 46 of 976 days (5%), with annual occurrences from <1% (1999-2000; 2005-2006) to 8-11% (2002, 2007). Cobia were only observed during one hour per day on 34 days (74%), two hours per day on 10 days (22%) and three-four hours per day on two days (4%). Thirty-seven percent of cobia observations occurred in Apr-Jun and also Oct-Dec; however, 24% of cobia observations occurred in Jul-Sep (2007 only). Eighty percent of cobia observations occurred when bottom water temperatures were between 65.4°F and 80.1°F (average = 71.2°F); wave heights between 1.4' and 6.5' (average = 3.4'); barometric pressures between 1006.6 and 1019.1 mb (average = 1013.5 mb); and salinities between 34.9 and 36.0 psu (average = 35.5 psu). Abundance indices were not significantly different with respect to time of day or tidal metrics (Appendix 5), nor with respect to moon phase and fraction illuminated (Appendix 6).

Cobia were associated with large, roughtail stingrays (*Dasyatis centroura*) in three of 10 day-hrs (all between November and January, once in July) when roughttail rays were seen. Association of cobia with large rays has long been known, and it is thought that cobia entering Chesapeake Bay follow large schools of rays during coast-wide migrations (Richards, 1967). Cobia were primarily seen as individuals; however, up to four cobia at a time were seen in our study.

Species Profile: Requiem sharks

Sandbar shark (1 of 3) co-occurring at the research site along with blue runner, 5 November 2002 14:00 hrs

Most small coastal sharks and many larger sharks found off SC are classified as Requiem sharks, and 10 of 16 SC saltwater game fish records for sharks belong to this family. Three species were consistently seen at the research site; however, because they were uncommon and due to similar appearances, blacktip sharks (*Carcharhinus limbatus*), spinners (*C. brevipinna*) and sandbar sharks (*C. plumbeus*) were analyzed together. All are slow-growing and long-lived; for example, sandbar sharks grow <3" per year and mature at a fork length of about 4.5' around 12 years old (Casey et al., 1985). Young are live-birthed; however, some species develop as eggs that remain inside of the mother until birth (Murdy et al., 1997). Requiem sharks are highly migratory, and adults are commonly tagged as part of the NMFS Cooperative Tagging Program as well as by recreational anglers in SC (Davy, 1994); however, detailed studies of local movement patterns have almost exclusively focused on juvenile sharks captured in nursery areas in the GOM (Heupel et al., 2003, 2004) and north of Cape Hatteras (Merson and Pratt, 2001; Conrath, 2006).

Requiem sharks were observed in 55 of 976 days (6%), with annual occurrences ranging from <1% (1999-2000; 2005-2006) to 8-11% (2002, 2007). Similar to cobia, sharks were only observed during one hour per day on 38 days (69%), two hours per day on 11 days (20%) and three-four hours per day on six days (11%). Sharks were most often seen in Oct-Dec (40%), about half as often (24%) in both Apr-Jun and Jul-Sep and least often (13%) in Jan-Mar. Eighty percent of observations occurred at bottom water temperatures of 71.0°F to 80.3°F (average = 75.3°F); wave heights of 1.4' to 5.9' (average = 3.4'); barometric pressures of 1008.4 to 1020.4 mb (average = 1013.8 mb); and salinities of 35.0 to 36.1 psu (average = 35.6 psu). Abundance indices were significantly greater on flooding tides, but not with respect to tide range, percent of tide stage elapsed or time of day (Appendix 5). Abundance indices were also not significantly different with respect to moon phase or fraction of the moon illuminated (Appendix 6).

Sharks co-occurred with at least one other pelagic finfish predator in 74% of day-hrs when sharks were seen. Greatest co-occurrence was associated with jacks, with amberjack and blue runner present in 40% and 33%, respectively, of the day-hrs when sharks were seen. Little tunny were present in 16% of day-hrs when sharks were seen, but sharks were less often (7%) seen with Great barracuda and cobia (1%). At oil platforms in the GOM, sharks are also associated with occurrence of blue runner and cobia (Stanley and Wilson, 1991).

Summary and Conclusions

Data collected by the remote video camera system in this study represent the best available data sets regarding mid-shelf seasonal occurrence and/or residence patterns for many reef and pelagic fishes commonly found in the South Atlantic Bight, despite intermittent camera operation, short sampling durations, and inability to distinguish specific individuals over time. Observations from this study also provide great insight into the variable nature of reef fish assemblages under as close to natural conditions as possible. As evidenced by this study, a variety of marine life utilizes artificial reefs, though seasonal use may differ among years. Remote monitoring also documented a much longer seasonal occurrence of highly migratory species such as Great barracuda, amberjacks and cobia off SC than previously reported. In particular, the occurrence of cobia at the study site in July may indicate that at least some portion of cobia found inshore in SC waters move offshore during the summer rather than migrating northward. Furthermore, the occurrence of all three species at the research site between late fall and early spring suggests that at least some portion of their respective populations may overwinter offshore, rather than traveling south to FL. Indeed, cobia have been collected from the middle to outer continental shelf off NC in the winter (Smith, 1995) and even 'cold-blooded reptiles' such as juvenile loggerhead sea turtles (Arendt et al., 2009) over-winter on the middle to outer continental shelf off SC and GA; thus, the suggestion of seasonal inshore-offshore movements as opposed to north-south movements are not unreasonable. With respect to cobia, resident and migratory populations are documented in the GOM (Franks et al., 1991) and a similar population structure has previously been suggested in the Atlantic (Hammond, 2001).

Benthic game fishes were seen with greater frequency than migratory pelagic predators; thus, visual abundance indices to assess seasonal and inter-annual changes for benthic fishes should be considered more reliable, particularly given the short sampling duration (i.e., 10-seconds) of video data files. Indices for black sea bass and gray triggerfish declined appreciably during the second half of the nine-year study, as did snapper and grouper which were seen with less frequently overall. Lower frequency of observation of snapper and grouper may reflect behavioral differences and activity patterns given that tide (snapper) and time of day (grouper) were associated with differences in abundance indices. Additionally, the tendency for non-spawning gag to associate in groups of fewer than ten individuals (Lindberg et al., 2006) may also preclude the formation of large numbers of gag at the research site. Atlantic spadefish were seasonally abundant at the mid-shelf reef; however, their overall occurrence declined throughout the study as well. In contrast, all but one observation of sheepshead occurred during the last year of the study; thus, persistent (albeit low) observation of a pair of sheepshead at the research site throughout the last year of the study suggests that they may have become established at or near the site eight years after it was created. Artificial reefs are thought to resemble natural reefs after just five years (Stone et al., 1979); however, studies of invertebrate communities among natural and artificial reefs more than 10 years old document greater invertebrate diversity at natural reefs (Burgess, 2008). Alternatively, it has been suggested (by the primary author of this report) that concentration of invertebrates on artificial reef units may ultimately lower invertebrate diversity at artificial reefs (where linear expansion is not possible), particularly when 'pickers and grazers' such as triggerfish, black sea bass and sheepshead occur in high densities. Indeed, over-grazing of invertebrates at the relatively small research site by black sea bass and triggerfish may have eventually led to a decline in their respective abundance indices in later years of this study.

Circumstantial evidence (a function of short-duration visual sampling) suggests that several reef fish species were reproductively active; thus, prior to the decline (regardless of the origin) in their abundance indices the reef contributed to their "production" rather than simply attraction. Aggregations of black sea bass were often seen hovering as a group 2-3m above the seafloor while facing into the current, and this seasonal activity may have been related to courtship and spawning in the late winter and early spring. Observations of groups of sea bass hovering off the bottom were not necessarily a prerequisite to spawning, but a strong social hierarchy is associated with black sea bass spawning (Nelson and Perry, 2003). Although not detailed in our results, sexually mature male 'gray-head' black sea bass were seen with increased frequency at the research site during periods when large groups of black sea bass were common in the late fall and spring, which coincided with spawning periods defined for this species using histology (Wenner et al., 1986); however, 'gray head males have also been observed in captivity year round and their presence does not exclusively indicate reproductive activity (M. Denson, SCDNR, personal communication). On several occasions, gray-head black sea bass were also seen chasing smaller (non-gray-head) black sea bass, perhaps in an attempt to maintain a harem and/or court females. Charcoal belly gag were seen paired with female gag extensively in spring 2007, with gag pairs remaining through the summer. Given the proximity of the research site to known recapture locations for reproductively-active gag tagged off the SC, the persistence of at least one mature pair of gag at the research site during spring and summer 2007 substantiates the suggestion that gag may have spawned there. Gray triggerfish may have also reproduced at the site, with increased observation in June 2004 associated with nest protection. Point-in-time video transects at similar habitats (type and water depth) in SC document gray triggerfish reproduction within five years of reef creation (Kolmos, 2007). Given these observations, remote video monitoring may offer a non-destructive means to assess social and visual cues for courtship and spawning, thereby complementing life history studies for many species.

Visual abundance indices increased appreciably during the study for tomtate, vermilion snapper and scad. The ability to at least occasionally distinguish small juvenile tomtate and vermilion snapper suggests that they may have been "produced" at the research site as well. Along with scad, the trophic importance of these abundant prey species in forming an ecological basis for the reef assemblage for both resident and transient species cannot be overstated. Predation pressure on these small fishes was believed to be sustained at a high level nearly year-round, with primary predators changing seasonally. Blue runner were frequently observed in large schools that persisted throughout daylight hours during the summer. Greater amberjack and great barracuda routinely patrolled the research site between spring and fall, and little tunny episodically exerted predation pressure during fall and winter. Large, slow-moving sharks were associated with foraging raids throughout the year as well, and may have benefited during these feeding events in much the same way that sea birds take advantage of schools of tuna driving forage species to the surface. Concurrent with the approach of large groups of pelagic predators, scad were effectively "herded" to very near the sea floor, as evidenced by frequent swarms of these species swimming in all directions near the cameras. However, it is also interesting to note that swams of these species persisted at the research site during the day even when reduced predation pressure was suggested. Nonetheless, daily changes in position these fishes with respect to reefs may predictably indicate changes in energy expenditure at the reef, both horizontally (tomtate) and vertically (vermilion, scad) as these fishes rest, feed and are fed upon.

In contrast to the ability to characterize when species were observed, our ability to explain why certain species were seen when they were was less successful. Interactions between different species (i.e., predator-prey relationships and competition for resources), as well as interactions among individuals of the same species (i.e., courtship and spawning) undoubtedly influence when certain fish are present and with what abundance levels; however, principal components analyses only weakly suggested that variation in abundance indices for a given species was influenced by occurrence of any other species examined, with the strongest grouping between tomtate, vermilion snapper, scad and mixed forage/juveniles. Weak relationships were also suggested by principal components analysis when species observations were examined collectively or one at a time with respect to environmental variables, of which water temperature, photoperiod, salinity and wave height were determined to be most important. Other studies have found stronger multi-variate relationships when fewer total observations and variables are used (Núñez-Lara and González, 1998; Eduardo et al., 2002 Gonzalez et al., 2008); however, those studies relied on consolidated (i.e., monthly representations) data which excludes fine-scale factors like tidal metrics and time of day. Given the significance of both tidal and time of day effects for several species in this study, we suggest that pooling data is actually counter-productive for trying to understand factors that influence species distributions at mid-shelf reefs. As evidenced by the inverse relationship between barometric pressure and tide stage in Figure 10 of this report, and by the graph of hourly barometric pressure data in Figure 23 below, environmental variables fluctuate daily with regular cycles that are episodically disrupted by other influences. Consequently, it may be possible to develop mathematical formulas or models that utilize meteorological and hydrographic data to 'predict' tide stage for locations on the mid-shelf where depth monitoring does not occur. Such predications could provide a valuable context for examining catch rate data, but would also be of great interest to fishers.
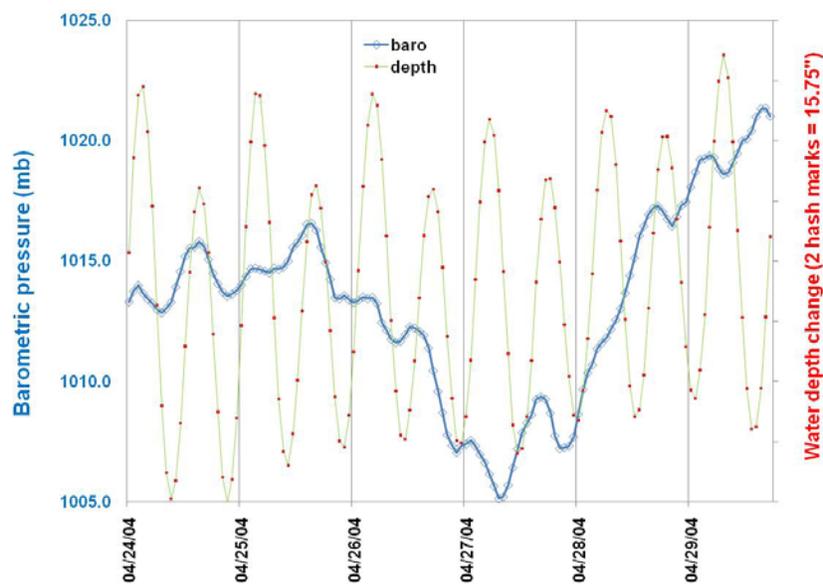
Figure 23. A snapshot of the potential relationship between barometric pressure and water depth on the mid-shelf between 24 and 29 April 2004 (average hourly data, courtesy of SKIO). Twice daily peaks in barometric pressure generally corresponded with high tide, though not always. Actual water depth levels are not shown in order to protect the location of the research site.

Inability to account for a large amount of variance in the data may have also stemmed from the inability to know for certain if non-observation of a species in a particular video represented a true absence from the research site or if it resulted from a species simply being out of the field of view at the time of the short (10-second) sampling event. In some instances, species may have actually left the reef for days at a time before returning, as evidenced by periods of non-observation for days at a time interspersed between days with consistent visual detection. In other instances, non-observation during a particular time of day may have been attributed to a dramatic change in activity or simply being just out of viewing range of the cameras at the time of sampling. As such, remote video data collection would have been greatly complemented by concurrent application of automated acoustic telemetry methods, to verify if acoustically-tagged individuals were present within a defined radius of the research site at the time of video sampling (as well as at night). Inclusion of this complementary technology would have also enabled documentation of occurrence of fish at the site that were tagged and released at other locations, for example cobia tagged in Port Royal Sound or sheepshead and red drum tagged at the Charleston jetties. Automated acoustic telemetry would also enable finer-scale detection of the influence of environmental variables. For instance, data collected using this technology revealed a relationship between falling barometric pressure in advance of a hurricane and departure of juvenile blacktip sharks from an estuary in SW FL (Heupel et al., 2003). As part of a mutually-beneficial relationship, remote video data collection would provide a visual indication of 'what was going on' during periods of exceptionally high or low fish detection events in the acoustic data set. Indeed, the creation of multi-faceted observational stations to study the co-occurrence of gag, their potential prey and detailed records of environmental conditions using a variety of remote sampling technologies is already underway in the NE GOM (Mason et al., 2006).

As demonstrated by the findings in this report, remote visual sampling in conjunction with other remote sampling methodologies has great merit and should be used to complement routine fisheries surveys where conditions of visibility are acceptable. Expanded spatial coverage of visual sampling at reef habitats located at similar depths and shelf position within the SAB could be accomplished through the use of a series of remote video data loggers. In addition to outreach and education benefits (Seim 2003) and a 'stand alone' value for characterizing changes in species assemblages, fisheries video data relate directly to on-going efforts to establish near real-time ocean observation networks, such as the Integrated and Sustained Ocean Observing System (IOOS; DeVoe et al. 2006) and could contribute high quality data for National Marine Fisheries Service ecosystem management and multi-species models. Collection of fisheries video data from a series of index stations at a variety of habitats across the continental shelf would greatly enhance our ability to model habitat/energy linkages, as well as to predict the responses of reef and pelagic fish assemblages to short- and long-term changes in oceanographic conditions. Expanded use of remote visual and other technologies could potentially permit future fisheries management to be based on near real-time data, to include estimates year class strengths as well as seasonal distribution data for a variety of marine species.

References

Allman, R.J. 2007. Small-scale spatial variation in the population structure of vermilion snapper (*Rhomboplites aurorubens*) from the northeast Gulf of Mexico. Fish. Res. 88(1-3): 88-99.

Arendt, M.D., J.E. Olney and J.A. Lucy. 2001. Stomach content analysis of cobia, *Rachycentron canadum*, from lower Chesapeake Bay. Fish. Bull. 99(4): 665-670.

Arendt, M., Byrd, J., Segars, A., Maier, P., Schwenter, J., Burgess, D., Boynton, J., Whitaker, J.D., Liguori, L., Parker, L., Owens, D., and Blanvillan, G. 2009. Examination of local movement and migratory behavior of sea turtles during spring and summer along the Atlantic coast off the southeastern United States. South Carolina Department of Natural Resources, University of Georgia, and College of Charleston, Final Report to NOAA Fisheries, Contract Number NA03NMF4720281, 177p.

Atkinson, L.P., J.O. Blanton and E.B. Haines. 1978. Shelf flushing rates based on the distribution of salinity and freshwater in the Georgia Bight. Estuar. Coast. Mar. Sci. 7: 465-472.

Benfield, M., S. Keenan, S. Powers, H. Brown, N. Geraldi and M. Sisak. 2005. Blue runner movement patterns and feeding ecology around a Gulf of Mexico petroleum platform. 135th Ann. Meeting of the Am. Fish Soc. Anchorage, Alaska; 11-15 Sept. 2005. (Abstract only). http://www.wdafs.org/Anchorage2005/afs/index.php

Benton, C.B. and D.L. Berlinsky. 2006. Induced sex change in black sea bass. J. Fish. Biol. 69: 1491-1503.

Berry, F.H. 1974. Blue runner, *Caranx crysos*. Pp.156-157, *In,* A.J. McClane, McClane's New Standard Fishing Encyclopedia and international angling guide. Holt, Rinehart and Winston, New York.

Blanton, J.O., L.P. Atkinson, L.J. Pietrafesa and T.N. Lee. 1981. The intrusion of Gulf Stream Water across the continental shelf due to topographically-induced upwelling. Deep Sea Res. 28A(4): 393-405.

Burgess, D.E. 2008. Development of invertebrate assemblages on artificial reef cones off South Carolina: comparison to an adjacent hard-bottom habitat. Unpublished Master's thesis, University of Charleston, Environmental Studies Program, Charleston, SC, 114p.

Bush, K.A. 1988. Identification of Savannah River water on the South Atlantic Bight Shelf Using Tritium. J. Geophys. Res. 93(C8): 9315-9331.

Byran, D.R., P.T. Arena, and R.E. Spieler. 2006. Preliminary comparisons between reef fish assemblages on vessel-reefs and natural substrate in depths of 70-95 meters. Proc. Gulf Caribb. Fish. Inst. 57:1009-1110.

Cabrera, M.A., O. Defeo, F. Aguilar and J. De Dios Martinez. 2005. The little tunny, (*Euthynnus alletteratus*) fishery of northeast Campeche Bank, Mexico. Proc. Gulf Caribb. Fish. Inst. 47: 744-758.

Campo, D., L. Castriota and M. Sinopoli. 2007. Annual trend of fish assemblages associated with FADs in the southern Tyrrhenian Sea. J. Appl. Icthyol./ Z. Angew. Ichthyol. 23(3): 258-263.

Carpenter, K.E. (ed.). 2002. The living marine resources of the Western Central Atlantic. Vol. 3. FAO Species identification guides for fishery purposes: Am. Soc. Ichthy. Herpt. Spec. Pub. 5:1375-2127. Rome, FAO.

Chapman, R.W. 1978. Observations of spawning behavior in Atlantic spadefish, *Chaetodipterus faber*. Copeia 1978(2): 336.

Chen, W.M., N. Umeda, T. Mitsuboshi and N. Hirazawa. 2007. Circadian self-feeding rhythms in greater amberjack, *Seriola dumerili* (Risso). J. Fish. Biol. 70(2): 451-461.

Conrath, C.L. 2006. Nursery delineation, movement patterns and migration of the sandbar shark, *Carcharhinus plumbeus*, in the eastern shore of Virginia coastal bays and lagoons. Unpublished Dissertation, College of William and Mary, School of Marine Science/VA Institute of Marine Science, Gloucester Point, VA.

Cuellar, N., G. R. Sedberry and D. M. Wyanski. 1996. Reproductive seasonality, maturation, fecundity, and spawning frequency of the vermilion snapper, *Rhomboplites aurorubens*, off the southeastern United States. Fishery Bulletin 94:635-653.

Darcy, G.H. 1983. Synopsis of biological data on the grunts *Haemulon aurolineatum* and *H. plumeri* (Pisces: Haemulidae). NOAA Technical Report, NMFS Circular 448, FAO Fisheries Synopsis 133:37 pp.

Davy, K.B. 1994. South Carolina marine game fish tagging program 1974-1992. South Carolina Marine Resources Division Technical Report 83, 136p.

de Andrade, C.E.R. 2007. Analysis of the biology, fishing and fishery potential of blue runner, *Carangoides crysos* (Cuvier, 1833) off Pernambuco State. Boletim Tecnico Cientifico du CEPENE 15(1): 89-95. (abstract only)

de Sylva, D.P. 1963. Systematics and life history of the great barracuda, *Sphyraena barracuda* (Walbaum). Studies in Tropical Oceanography. No.1, Univ. Miami Press. Coral Gables, Florida. 179 p.

DeVoe, M.R., E. Buckley, J. Dorton, M. Fletcher, L. Leonard, P. Lumpkin, C.N.K Mooers, L.J. Pietrafesa, D. Porter, H. Seim, S. Sheldon and L. Xie. 2006. Regional Coastal IOOS development in the Southeastern United States: Emerging capabilities to address coastal natural hazards. Mar. Technol. Soc. J. 40(4): 119-119.

Ditty, J.G., R.F. Shaw, and J.S. Cope. 2004. Distribution of carangid larvae (Teleostei: Carangidae) and concentrations of zooplankton in the northern Gulf of Mexico, with illustrations of early *Hemicaranx amblyrhynchus* and *Caranx* spp. Larvae. Mar. Biol. 145: 1001-1014.

Dooley, J.K. 1972. Fishes associated with the pelagic *Sargassum* complex, with a discussion of the *Sargassum* community. Contrib. Mar. Sci. 72:1-32.

Dorenbosch, M., M.C. van Riel, I. Nagelkerken and G. van der Velde. 2004. The relationship of reef fish densities to the proximity of mangrove and seagrass nurseries. Estuar. Coast. Shelf Sci. 60(1):37-48.

Durie, C.J. and R.G. Turingan. 2001. Relationship between durophagy and feeding biomechanics in gray triggerfish, *Balistes capriscus:* Intraspecific variation in ecological morphology. Florida Scientist 64(1):20-28.

Eduardo, A.S., T. Godoy, C.M. Almeida and I.R. Zalmon. 2002. Fish assemblages and environmental variables on an artificial reef north of Rio de Janeiro, Brazil. ICES J. Mar. Sci. 59(s): 138-143.

Fable, W.A. Jr.1980. Tagging studies of red snapper (*Lutjanus campechanus*) and vermilion snapper (*Rhomboplites aurorubens*) off the south Texas coast. Contrib. Mar. Sci. Univ. Texas. 23:115-121.

Fabrizio, M.C., J.P. Pessutti, J.P. Manderson, A.F. Drohan and B.A. Phelan. 2005. Use of historic area remediation site by black sea bass and summer flounder. NE. Fish. Ctr. Ref. Doc. 05-06, 95p.

Faunce, C.H., and J.E. Serafy. 2008. Selective use of mangrove shorelines by snappers, grunts and great barracuda. Mar. Ecol. Prog. Ser. 356: 153-162.

Franks, J.S., M.H. Zuber and T. DmcIlwain. 1991. Trends in seasonal movements of cobia, *Rachycentron canadum*, tagged and released in the northern Gulf of Mexico. J. Miss. Acad. Sci. 36(1): 55.

Franks, J.S., N.K. Garber and J.R. Warrend. 1996. Stomach contents of juvenile cobia, *Rachycentron canadum*, from the northern Gulf of Mexico. Fish. Bull. 94(2): 374-380.

Franks,J.S. and N.J. Brown-Peterson, 2002. A review of age, growth and reproduction of cobia, *Rachycentron canadum*, from U.S. watrs of the Gulf of Mexico and Atlantic Ocean. Proc. Gulf. Carib. Fish. Inst. 53: 553-569.

Gallaway, B.J., M.F. Johnson, R.L. Howard, L.R. Martin and G.S. Boland. 1979. A study of the effects of Buccaneer oil field structures and associated effluents on biofouling communities and the Atlantic spadefish (<u>*Chaetodipterus faber*</u>). *In*: Environmental assessment of an active oil field in the northwestern Gulf of Mexico, 1977-1978. Vol. 2:

Data management and biological investigations. NOAA/NMFS; Galveston, TX (USA).
136 p.

Gilmore, R.G. and R.S. Jones. 1992. Color variation and associated behavior in the Epinepheline
groupers, *Mycteropreca microlepis* (Goode and Bean) and *M. phenax* Jordan and Swain.
Bull. Mar. Sci. 51(1): 83-103.

Gledhill, C. 2005. A fisheries acoustic survey of reef fish within two marine protected areas on
the west Florida shelf. Proc. Gulf Caribb. Fish. Inst. 56:424-425.

Gold, J.R. and L.R. Richardson. 1998. Population structure in greater amberjack, *Seriola
dumerili*, from the Gulf of Mexico and the western Atlantic Ocean. Fish. Bull. 96(4):
767-778.

Gonzalez, L.W., N. Eslava, J. Suniaga and F. Guevara. 2008. Association of environmental
variacles with Little tunny (*Euthynnus alletteratus*) fisheries off Margarita Island,
Venezuela. Bol. Cent. Invest. Biol. (Maracaibo), 42(3): 387-396 (Abstract only)

Goodwin, J.M. IV, and J.H. Finucane. 1985. Reproductive biology of blue runner (*Caranx
crysos*) from the eastern Gulf of Mexico. NE Gulf Sci. 7(2): 139-146.

Goodwin, J.M., IV, and A.G. Johnson. 1986. Age, growth, and mortality of blue runner, *Caranx
crysos*, from the northeastern Gulf of Mexico. NE Gulf Sci. 8(2):107-114.

Grimes, C.B., C.S. Manooch, III and G.R. Huntsman. 1982. Reef and rock outcropping fishes
in the outer continental shelf of North Carolina and South Carolina, and ecological notes
on the red porgy and vermilion snapper. Bull. Mar. Sci., 32:277-289.

Hammond, D.L. 2001. Status of the South Carolina fisheries for cobia. South Carolina
Department of Natural Resources, Marine Resources Division Technical Report Number
89, Charleston, SC, 22p.

Hare, J.A., D.E. Hoss, A.B. Powell, M. Konieczna, D.S. Peters, S.R. Cummings and R. Robbins.
2001. Larval distribution and abundance of the family Scombridae and
Scombrolabracidae in the vicinity of Puerto Rico (Mexico) and the Virgin Islands (United
States). Bull. Sea. Fish. Inst. Gdynia 153: 13-29.

Harris, P.J. and M.R. Collins. 2000. Age, growth and age at maturity of gag, *Mycteroperca
microlepis*, from the southeastern United States during 2994-1995. Bull. Mar. Sci. 66(1):
105-117.

Harris, P.J., D.M. Wyanski, D.M. White and J.L. Moore. 2002 Age, growth and reproduction of
Scamp, *Mycteroperca phenax*, in the southwestern North Atlantic, 1979-1997, Bull. Mar.
Sci. 70 (1): 113-132.

Harris, P.J., D.M. Wyanski, D.B. White, P.P. Mikell, and P.B. Eyo. 2007. Age, growth and reproduction of greater amberjack off the Southeastern U.S. Atlantic Coast. Trans. Am. Fish. Soc. 136(6): 1534-1545.

Hayes, J.W. 1989. Feeding habits, age, growth and reproduction of Atlantic spadefish, *Chaetodipterus faber* (Pisces: Ephippidae) in South Carolina. Fish. Bull. 88:67-83.

Heupel, M.R., C.A. Simpfendorfer and R.E. Heuter. 2003. Running before the storm: blacktip sharks respond to falling barometric pressure associated with Tropical Storm Gabrielle. J. Fish. Biol. 63(5): 1357-1363.

Heupel, M.R., C.A. Simpfendorfer and R.E. Heuter. 2004. Estimation of shark home ranges using passive monitoring techniques. Env. Bio. Fish 71(2): 135-142.

Hoffmayer, E.R., J.S. Franks, W.B.Driggers III, K.J. Oswald and J.M. Quattro. 2007. Observations of a feeding aggregation of whale sharks, *Rhincodon typus*, in north central Gulf of Mexico. Gulf. Caribb. Res. 19(2): 69-73.

Ingram, G.W. and W.F. Patterson. III. 2001. Movement patterns of red snapper (*Lutjanus campechanus*), greater amberjack (*Seriola dumerili*) and gray triggerfish (*Balistes capriscus*) in the Gulf of Mexico and the utility of marine reserves as management tools. Proc. Gulf Caribb. Fish. Inst. 52:686-699.

Joseph, E.B., J.J. Norcross and W.H. Massmann. 1964. Spawning of cobia, *Rachycentron canadum*, in the Chesapeake Bay area, with observations of juvenile specimens. Ches. Sci 5: 67-71.

Johnson, A. and C. Saloman. 1984. Age, growth and mortality of gray triggerfish, *Balistes capriscus*, from the northern Gulf of Mexico. Fish. Bull. 82: 485-492.

Kahraman, A.E. and I.K. Oray. 2001. The determination of age and growth parameters of Atlantic little tunny *Euthynnus alleteratus* (Rafinesque, 1810). Internatl. Comm.Conserv. Atlantic Tuna; Coll. Vol. Sci. Papers 52: 719-732.

Kauppert, P.A. 2002. Feeding habits and trophic relationships at an assemblage of fishes associated with a newly established artificial reef off South Carolina. College of Charleston Master's thesis, Charleston, SC. 123 pp.

Keenan, S.F., M.C. Benfield, and R.F. Shaw. 2003. Zooplanktivory by blue runner *Caranx crysos*: a potential energetic subsidy to Gulf of Mexico fish populations at petroleum platforms. Am. Fish. Soc. Symp. 36: 167-180.

Kendall, M.S., L.J. Bauer, and C.F.G. Jeffery. 2008. Influence of benthic features and fishing pressure on size and distribution of three exploited reef fishes from the southeastern United States. Trans. Am. Fish. Soc. 137(4): 1134-1146.

Koenig, C.C., F.C. Coleman, L.A. Collins, Y. Sadovy and P.L. Colin. 1996. Reproduction of gag (*Myteroperca microlepis* (Pisces: Serranidae) in the eastern Gulf of Mexico and the consequences of fishing spawning aggregations. Biology, Fisheries and Culture of Tropical Groupers and Snappers, pp. 307-323. ICLARM Conf. Proc. 48.

Kolmos, K.J. 2007. Succession and biodiversity of an artificial reef marine protected area: A comparison of fish assemblages on protected and unprotected habitats. Unpublished Master's thesis, University of Charleston, Grice Marine Biological Laboratory, Charleston, SC, 79p.

Kurz, R.C. 1995. Predator-prey interactions between gray triggerfish (*Balistes capriscus* Gmelin) and a guild of sand dollars around artificial reefs in the northeastern Gulf of Mexico. Bull. Mar. Sci. 56(1): 150-160.

Lindberg, W.J., T.K. Frazer, K.M. Portier, F. Vose, J. Loftin, D.J. Murie, D.M. Mason, B. Nagy, and M.K. Hart. 2006. Density-dependent habitat selection and performance by a large mobile reef fish. Ecol. App. 16(2):731-746.

Lindquist, D.G., L.B. Cahoon, I.E. Clavijo, M.H. Posey, S.K. Bolden, L.A. Pike, S.W. Burk and P.A. Cardullo. 1994. Reef fish stomach contents and prey abundance on reef and sand substrata associated with adjacent artificial and natural reefs in Onslow Bay, North Carolina. Bull. Mar. Sci. 55(2-3): 308-318.

Low, R.A., Jr., and C.W. Waltz. 1991. Seasonal utilization and movement of black sea bass on a South Carolina artificial reef. N. Am. J. Fish. Mgmt. 11: 131-138.

Lucy, J.A. and C.M. Bain, III. 2003. Virginia Game Fish Tagging Program Annual Report, 2002. Virginia Marine Resource Report No. 2003-05, VSG-03-17, 51p. plus Appendices (17p.).

Lucy, J.A. and C.M. Bain, III. 2007. Virginia Game Fish Tagging Program Annual Report, 2007. Virginia Marine Resources Report No. 2007-1, VSG-07-1, 59 p. plus Appendices (37 p.)

MacKichan, C.A. and S.T. Szedlmayer. 2006. Reproductive behavior of the gray triggerfish, *Balistes capriscus*, in the Northeastern Gulf of Mexico. 59th Annual Gulf and Caribbean Fisheries Institute Conference, Belize, 6-11 November 2006.

Manooch, C.S. III, and M. Haimovici. 1978. Age and growth of gag, *Mycteroperca microlepis*, and size-age composition of the recreational catch off the southeastern United States. Trans. Am. Fish. Soc. 107(2): 234-240.

Manooch, C.S. III, and C.A. Barans. 1982. Distribution, abundance and age and growth of the tomtate, *Haemulon aurolineatum*, along the southeastern United States coast. U.S. Fish Wildl. Ser. Fish. Bull. 80(1): 1-19.

Manooch, C.S. III, D.L. Mason and R.S. Nelson. 1985. Foods of little tunny *Euthynnus alletteratus* collected along the southeastern and Gulf coasts of the United States. Bull. Jap. Soc. Sci. Fish. 51(8): 1207-1218.

Manooch, C.S. III, and J.C. Potts. 1997. Age and growth of red snapper, *Lutjanus campechanus*, Lutjanidae, Collected along the southeastern United States from North Carolina through the east coast of Florida. J. Elisha Mitchell Sci. Soc. 113(3): 111-122.

Masuda, R., K. Keller, D.A. Ziemann and J. Ogle. 2003. Association with underwater structures in hatchery-reared and wild red snapper *Lutjanus campechanus* juveniles. J. World Aquacult. Soc. 34(2): 140-146.

Matheson, R.H. III, G.R. Huntsman and C.S. Manooch III. 1986. Age, growth, mortality, food and reproduction of the scamp, *Mycteroperca phenax*, collected off North Carolina and South Carolina. Bull. Mar. Sci. 38 (2): 300-312.

Mason, D.M., B. Nagy, M. Butler, S. Larsen, D.J. Murie and W.J. Lindberg. 2005. Integration of Technologies for Understanding the Functional Relationship Between Reef Habitat and Fish Growth and Production. Proc. Gulf Carib. Fish. Inst. 56: 427-428.

Matthews, T.D. and O. Pashuk. 1986. Summer and winter hydrography of the U.S. South Atlantic Bight (1973-1979). J. Coast. Res. 2(3): 311-366.

McCawley, J.R., J.H. Cowan, Jr., and R.L. Shipp. 2006. Feeding periodicity and prey habitat preference of red snapper, *Lutjanus campechanus* (Poey, 1860), on Alabama artificial reefs. Gulf Mex. Sci. 24(1-2): 14-27.

McClellan, D.B., and N.J. Cummings. 1997. Preliminary analysis of tag and recapture data of the greater amberjack, *Seriola dumerili*, in the southeastern United States. Proc. Gulf. Carib. Fish. Inst. 49: 25-45.

McGovern, J.C., G.R. Sedberry and P.J. Harris. 1998a. The status of the fish stocks off the southeast United States, 1983-1996. Proc. Gulf Caribb. Fish. Inst. 50: 871-895.

McGovern, J.C., D.M. Wyanski, O. Pashuk, C.S. Manooch, III, and G.R. Sedberry. 1998b. Changes in the sex ratio and size at maturity of gag, *Mycteroperca microlepis*, from the Atlantic coast of the southeastern United States during 1976-1995. Fish. Bull. 96:797-807.

McGovern, J.C., M.R. Collins, O. Pashuk, and H.S. Meister. 2002. Temporal and spatial differences in life history parameters of black sea bass in the southeastern United States. N. Am J. Fish Manage. 22: 1151-1163.

McGovern, J.C., G.R. Sedberry, H.S. Meister, T.M. Westendorff, D.M. Wyanski and P.J. Harris. 2005. A tag and recapture study of gag, *Mycteroperca microlepis*, off the Southeastern U.S. Bull. Mar. Sci. 76(1): 47-59.

Merson, R.R. and H.L. Pratt, Jr. 2001. Distribution, movements and growth of young sandbar sharks, *Carcharhinus plumbeus*, in the nursery grounds of Delaware Bay. Env. Bio. Fish. 61(1): 13-24.

Meyer, G.H. and J.S. Franks. 1996. Food of cobia, *Rachycentron canadum*, from the north-central Gulf of Mexico. Gulf. Res. Rep. 9(3): 161-167.

Mikell, P.P., J.A. Stephen, C.A. Barans and P.J. Harris. *In Prep*. Assessing age, growth, and reproduction in the tomtate, *Haemulon aurolineatum*, in the South Atlantic Bight.

Mikell, P. P., M. J. M. Reichert and J. A. Stephen. 2007. Analytical Report in prep. Age, growth, and reproductive biology of vermilion snapper, *Rhomboplites aurorubens*, from the southeastern United States, 2002-2005.

Moe, M.A., Jr., D.S. Beaumariage and R.W. Topp. 1970. Return of tagged gag, *Mycteroperca microlepis*, and Caribbean Red Snapper, *Lutjanus campechanus*, after six years of freedom. Trans. Am. Fish. Soc. 1970(2): 428-429.

Moore, J.L. 2001. Age, growth and reproductive biology of the gray triggerfish (*Balistes capriscus*) from the southeastern United States, 1992-1997. Unpublished Master's Thesis, University of Charleston, Charleston, South Carolina. 69p.

Murdy, E.O., R.S. Birdsong and J.A. Musick. 1997. Fishes of the Chesapeake Bay. Smithsonian Institution Press, Washington, D.C., 324p.

Musick, J.A., and L.P. Mercer. 1977. Seasonal distribution of black sea bass, *Centorpristis striata*, in the mid-Atlantic Bight with comments on the ecology and fisheries of the species. Trans. Am. Fish. Soc. 106(1): 12-25.

Nagelkerken, I. and G. van der Velde. 2004. Are Caribbean mangroves important feeding grounds for juvenile reef fish from adjacent seagrass beds? Mar. Ecol. Prog. Ser. 274: 143-151.

National Weather Service (NWS), 1. What are El Niño, La Niña, and ENSO? http://www.nws.noaa.gov/om/brochures/climate/El_NinoPublic.pdf

National Weather Service (NWS), 2. Cold and warm episodes by season. http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

Nelson, D.A. and D. Perry. 2003. pp. 297-298 *In* Natural spawning of black sea bass, *Centropristis striata*, at the NMFS Milford Laboratory and the UMASS Dartmouth Laboratory with observations on spawning behavior. Milford Aquaculture Seminar, Milford Connecticut, February 2003.

Núñez-Lara, E. and E.A. González. 1998. The relationship between reef fish community structure and environmental variables in the southern Mexican Caribbean. J. Fish Biol. 53(A): 209-221.

Ogden, J.C., and P.R. Ehrlich. 1977. The Behavior of Heterotypic Resting Schools of Juvenile Grunts (Pomadasyidae). Marine Biology, 42:273-280.

Parker, R.O. Jr. 1990. Tagging studies and diver observations of fish populations on live-bottom reefs of the U.S. Southeastern coast. Bull. Mar. Sci. 46 (3): 749-760.

Parker, R.O., Jr., A.J. Chester and R.S. Nelson. 1994. A video transect method for estimating reef fish abundance, composition, and habitat utilization at Gray's Reef National Marine Sanctuary, Georgia. Fish. Bull. 92(4): 787-799.

Patterson, W.F., III, J.C. Watterson, R.L. Shipp and J.H. Cowan, Jr. 2001. Movement of tagged red snapper in the northern Gulf of Mexico. Trans. Am. Fish. Soc. 130(4): 533-545.

Potts, J.C., C.S. Manooch III and D.S. Vaughn. 1998. Age and growth of vermilion snapper from the Southeastern United States. Trans. Am. Fish. Soc. 127 (5):787-795.

Richards, C.E. 1967. Age, growth, and fecundity of the cobia, *Rachycentron canadum*, from Chesapeake Bay and adjacent mid-Atlantic waters. Trans. Am. Fish. Soc. 96(3): 343-350.

Robbins, C.G., C.G. Ray and J. Douglass. 1986. A field guide to Atlantic Coast fishes, North America. Houghton Mifflin Company, Boston, MA, 354p.

Rountree, R.A. 1990. Community structure of fishes attracted to shallow water fish aggregation devices off South Carolina, U.S.A. Env. Bio. Fish. 29(4): 241-262.

Rudershausen, P.J., E.H. Williams, J.A. Buckel, J.C. Potts, and C.S. Manooch, III. 2008. Comparison of reef fish catch per unit effort and total mortality between the 1970's and 2005-2006 in Onslow Bay, North Carolina. Trans. Am. Fish. Soc. 137(5): 1389-1405.

Sauskan, V.I., and A. Olaechea. 1974. Biology and population abundance of the tomtate (*Haemulon aurolineatum* Cuvier and Valenciennes, 1830, Pomadasidae, Perciformes) on Campeche Bank. *In* A.S. Bogdanov (ed.), Sovetsko-Kubinskiye ryb. Issled (Soviet-Cuban fishery investigations) 4: 135-150. Moscow. (translated by Oleg Pashuk)

Schaffer, R.V. and E.L. Nakamura. 1989. Synopsis of biological data on the cobia, *Rachycentron canadum* (Pisces: Rachycentridae). U.S. Dept. of Commer., NOAA Tech Rep NMFS 82 (FAO Fisheries Synopsis 153), 21p.

Schmidt, T.W. 1989. Food habits, length-weight relationships and condition factor of young great barracuda, *Syphraena barracuda* (Walbaum), from Florida Bay, Everglades National Park, Florida. Bull. Mar. Sci. 44(1):163-170.

Schobernd, C.M. and G.R. Sedberry. 2009. Shelf-edge and upper-slope reef fish assemblages in the South Atlantic Bight: Habitat characteristics, spatial variation, and reproductive behavior. Bull. Mar. Sci. 84(1): 67-92.

Schroepfer, R.L. and S.T. Szedlmayer. 2006. Estimates of residence and site fidelity for red snapper, *Lutjanus campechanus*, on artificial reefs in the northeastern Gulf of Mexico. Bull. Mar. Sci. 78(1): 93-101.

Schwartz, F.J. 1998. Biological and ecological relationships for young Atlantic spadefish, *Chaetodipterus faber*, (Pisces: Family Ephippidae) collected in the Cape Fear River estuary and adjacent waters, North Carolina, 1973 through 1978. J. Elisha Mitchell Sci. Soc. 114(1): 23-30.

Sedberry G.R. and R.F. Van Dolah. 1984. Demersal fish assemblages associated with hard bottom habitat in the South Atlantic Bight of the USA. Env. Biol. Fishes. 11:241-258.

Sedberry, G.R. 1985. Food and feeding of the tomtate, *Haeumlon aurolineatun* (Pisces, Haemulidae), in the South Atlantic Bight. U.S. Fish Wildl. Ser. Fish. Bull. 83(3): 461-466.

Sedberry, G.R. 1988. Food and feeding of Black sea bass, *Centropristis striata*, in live bottom habitats in the South Atlantic Bight. J. Elisha Mitchell Sci. Soc. 104(2):35-50.

Sedberry, G.R. and N. Cuellar. 1993. Planktonic and benthic feeding by the reef-associated vermilion snapper, *Rhomboplites aurorubens*, (Teleostei, Lutjanidae). Fish. Bull. 91(4):699-709.

Sedberry, G.R., J.C. McGovern and C.A. Barans. 1998. A comparison of fish populations in Gray's Reef National Marine Sanctuary to similar habitats off the southeastern U.S.: Implications for the reef fish and sanctuary management. Proc. Gulf Caribb. Fish. Inst. 50: 452-481.

Seim, H. 2003, SEA-COOS: A model for a multi-state, multi-institutional regional observation system. Mar. Technol. Soc. J. 37(3): 92-101.

Smith, C.L. and Tyler J.C. 1973. Population ecology of a Bahamian suprabenthic shore fish assemblage. Am. Mus. Nov. 2528: 1-37.

Smith, J.W. 1995. Life history of cobia, *Rachycentron canadum* (Osteichthyes: Rachycentridae), in North Carolina waters. Brimleyana, 23: 1-23.

South Carolina Department of Natural Resources (SCDNR). 2003. "Drought officially over in state, Committee says." Special News Release #03-18, 24 April 2003.

Springer, V.G., and A.J. McErlean. 1961. Tagging of great barracuda, *Sphyraena barracuda* (Walbaum).Trans. Am. Fish. Soc. 90(4): 497-500.

Stanley, D.R., C.A. Wilson. 1991. Factors affecting the abundance of selected fishes near oil and gas platforms in the northern Gulf of Mexico. Fish. Bull. 89: 149-159.

Stanley, D.R. and C.A. Wilson. 2003. Seasonal and spatial variation in biomass and size frequency distribution of fish associated with oil and gas platforms in the northern Gulf of Mexico. Fisheries, Reefs and offshore Development. Am Fish Soc. Symp. 36: 123-136.

Steimle, F.W. and W. Figley. 1996. The importance of artificial reef epifauna to black sea bass diets in the middle Atlantic Bight. N. Am. J. Fish. Manage. 16: 433-439.

Steimle, F.W., C.A. Zetlin, P.L. Berrien, and S. Chang. 1999. Black sea bass, *Centropristis striata*, life history and habitat characteristics. NOAA Tech. Momo. NMFS-NE-143. U.S. Dept. Commerce. Woods Hole, Mass. 14 p.

Stone, R.B., H.L. Pratt, R.O. Parker, Jr and J.E. Davis. 1979. A comparison of fish populations on an artificial and natural reef in the Florida Keys. Mar. Fish. Rev. 41(9): 1-11.

Struhsaker, P. 1969. Demersal fish resources: Composition, distribution and commercial potential of the continental shelf stocks off southeastern United States. USFWS, Fish. Ind. Res. 4: 261-300.

Szedlmayer, S.T. 1997. Ultrasonic telemetry of red snapper, *Lutjanus campechanus*, at artificial reef sites in the northeast Gulf of Mexico. Copeia 1997:846-850.

Szedlmayer, S.T. and R.L. Schroepfer. 2005. Long-term residence of red snapper on artificial reefs in the northeastern Gulf of Mexico. Trans. Am. Fish. Soc. 134(2): 315-325.

Thompson, B.A., M. Beasley and C.A. Wilson. 1999. Age distribution and growth of greater amberjack, *Seriola dumerili*, from the north-central Gulf of Mexico. Fish. Bull. 97(2): 362-371.

Tremain, D.M., C.W. Harnden and D.W. Adams. 2004. Multidirectional movements of sportfish species between and estuarine no-take zone and surrounding waters of the Indian River Lagoon, Florida. Fish. Bull. 102(3): 533-544.

Trent, L. D.E. Parshley and J.K. Carlson. 1997. Catch and by-catch in the shark drift gill net fishery off Georgia and east Florida. Mar. Fish. Rev. 59(1): 19-28.

Tringali, M.D. and M. Higham. 2007. Isolation-by-distance gene flow among vermilion snapper (*Rhomboplites aruorubens* / Cuvier, 1829) from the Gulf of Mexico and southeastern United States. Gulf. Mex. Sci. 25 (1): 2-14.

Wade, C.W. 1978. Studies of migratory patterns of commercially valuable marine finfish of Alabama. Al. Dept. Conser. Nat. Resour. Compl. Rept. 12p. Montgomery, AL

Watterson, J.C., W.F. Patterson, III, R.L Shipp, and J.H. Cowan, Jr. 1998. Movement of red snapper, *Lutjanus campechanus*, in the north central Gulf of Mexico: Potential effects of hurricanes. Gulf Mex. Sci. 16(1):92-104.

Wells, R.J.D. and J.R. Rooker. 2004. Spatial and temporal patterns of habitat use by fishes associated with *Sargassum* mats in the Northwestern Gulf of Mexico. Bull. Mar. Sci. 74(1): 81-99.

Wenner, C.A., W.A. Roumillat, and C.W. Waltz. 1986. Contributions to the life history of black sea bass, *Centropristis striata*, off the southeastern United States. Fish. Bull. 84(3): 723-741.

Wenner, C.A. and J. Archambault. 2006. The natural life history and fishing techniques for sheepshead in South Carolina. SCDNR Education Report Number 23, Charleston, SC, 28p.

White, D.B., and S.M. Palmer. 2004. Age, growth, and reproduction of the red snapper, *Lutjanus campechanus*, from the Atlantic waters of the southeastern U.S. Bull. Mar. Sci. 75(3): 335-360.

Wickham, D.A., J.W. Watson and L.H. Orgen. 1973. The efficacy of mid-water artificial structures for attracting pelagic sport fish. Trans. Am. Fish. Soc. 102(3): 563-572.

Wilson, S.K., D.T. Wilson, C. Lamont and M. Evans. 2006. Identifying individual great barracuda, *Sphyraena barracuda*, using natural body marks. J. Fish. Biol. 69(3): 928-932.

Appendix 1. Results of K-W rank and Dunn's testing for annual and seasonal differences.

	Black sea bass, Atlantic spadefish, Gray triggerfish, Sheepshead, Grouper, Snapper	Tomtate and Vermilion snapper	forage/juvenile/scad	Blue runner, Amberjacks, Great barracuda, Little tunny, Cobia, Requiem sharks
	seasons	**seasons**	**seasons**	**seasons**
df	3	3	3	3
H	421.59	1099.65	505.16	789.67
p-value	<0.001	<0.001	<0.001	<0.001
trend	Jan-Mar > Apr-Jun > Oct-Dec > Jul-Sep	Jul-Sep > Oct-Dec > Jan-Mar > Apr-Jun	Jul-Sep > Oct-Dec > Jan-Jun	Jul-Sep > Oct-Dec > Apr-Jun > Jan-Mar
	year by winter	**year by winter**	**year by winter**	**year by winter**
df	4	4	4	4
H	294.93	579.93	449.97	54.94
p-value	<0.001	<0.001	<0.001	<0.001
trend	04 > 05 & 07 > 00 > 08	08 > 07 > 00, 04 & 05	08 > 07 > 04 & 00 > 05	00 > 08 > 07, 04 & 05
	year by spring	**year by spring**	**year by spring**	**year by spring**
df	4	4	4	4
H	203.15	857.62	785.36	196.09
p-value	<0.001	<0.001	<0.001	<0.001
trend	04 > 00 & 05 > 07 > 08	08 > 07 > 00 > 04 & 05	07 > 08 > 00, 04 & 05	08 > 07 & 04 > 00 & 05
	year by summer	**year by summer**	**year by summer**	**year by summer**
df	7	7	7	7
H	393.28	529.26	246.2	294.44
p-value	<0.001	<0.001	<0.001	<0.001
trend	04 & 07 > 00 & 02 > 99, 05, 06 & 08	07 > 08 > 05 > 00 > 99, 02, 04 & 06	08, 05-07 > 99, 00, 02 & 04	05 & 07 > 99 > 06 & 04 > 08, 02 & 00
	year by fall	**year by fall**	**year by fall**	**year by fall**
df	5	5	5	5
H	201.21	497.6	660.16	97.16
p-value	<0.001	<0.001	<0.001	<0.001
trend	04 & 02 > 07, 00 & 99 > 06	07 > 06 > 99, 00, 02 & 04	07 > 06 > 02 > 99,00 & 04	04 > 07 & 02 > 06, 00 & 99

	Black sea bass	Gray triggerfish	Atlantic spadefish
	seasons	**seasons**	**seasons**
df	3	3	3
H	293.07	84.03	893.94
p-value	<0.001	<0.001	<0.001
trend	Jan-Mar & Oct-Dec > Apr-Jun > Jul-Sep	Oct-Dec > Apr-Jun > Jan-Mar & Jul-Sep	Jan-Mar > Apr-Jun > Jul-Sep > Oct-Dec
	year by winter	**year by winter**	**year by winter**
df	4	4	4
H	93.39	95.59	195.25
p-value	<0.001	<0.001	<0.001
trend	04 > 00 > 05, 07 & 08	04 > 00 & 05 > 07 & 08	07, 05 & 04 > 00 & 08
	year by spring	**year by spring**	**year by spring**
df	4	4	4
H	607.15	164.11	42.05
p-value	<0.001	<0.001	<0.001
trend	04 > 00 > 05, 07 & 08	04 > 00 & 05 > 07 & 08	05, 04 & 00 > 07 & 08
	year by summer	**year by summer**	**year by summer**
df	7	7	7
H	544.3	123.2	129.55
p-value	<0.001	<0.001	<0.001
trend	04 > 02 > 00 > 99, 05-08	06, 04, 02 & 00 > 99, 05, 07-08	06-07 & 00 > 08 > 04-05, 02 & 99
	year by fall	**year by fall**	**year by fall**
df	5	5	5
H	216.34	92.59	90.25
p-value	<0.001	<0.001	<0.001
trend	04, 02 & 00 > 99, 06-07	04 & 02 > 99, 00 & 06-07	99 > 04 > 02 & 00 > 06-07

Appendix 1, continued

	Snappers	Groupers	Tomtate
	seasons	**seasons**	**seasons**
df	3	3	3
H	87.01	65.3	780.43
p-value	<0.001	<0.001	<0.001
trend	Oct-Dec & Apr-Jun > Jan-Mar & Jul-Sep	Oct-Dec > Jul-Sep & Jan-Mar > Apr-Jun	Jul-Sep > Jan-Mar & Oct-Dec > Apr-Jun
	year by winter	**year by winter**	**year by winter**
df	4	4	4
H	28.59	157.51	569.94
p-value	<0.001	<0.001	<0.001
trend	05 > 00, 04 & 07-08	05 > 07 > 08, 04 & 00	08 > 07 > 00 & 04-05
	year by spring	**year by spring**	**year by spring**
df	4	4	4
H	50.04	339.31	1029.74
p-value	<0.001	<0.001	<0.001
trend	08 & 05 > 07, 04 & 00	05 > 07 > 08, 04 & 00	08 > 07 > 00 & 04-05
	year by summer	**year by summer**	**year by summer**
df	7	7	7
H	21.88	600.48	444.35
p-value	<0.001	<0.001	<0.001
trend	02 > 99-00 & 04-08	02 & 07 > 99,00, 04-06 & 08	07-08 > 05 & 00 > 06, 04, 02 & 99
	year by fall	**year by fall**	**year by fall**
df	5	5	5
H	48.82	81.7	722.32
p-value	<0.001	<0.001	<0.001
trend	04 > 99-00, 02 & 06-07	02, 07 & 04 > 99-00 & 06	07 > 99-00, 02 & 04 > 06

	Vermilion	Mixed Forage/Juveniles	Scad
	seasons	**seasons**	**seasons**
df	3	3	3
H	1100.44	477.98	213.63
p-value	<0.001	<0.001	<0.001
trend	Jul-Sep > Oct-Dec > Jan-Mar & Apr-Jun	Jul-Sep > Oct-Dec > Apr-Jun > Jan-Mar	Jul-Sep & Oct-Dec > Jan-Mar > Apr-Jun
	year by winter	**year by winter**	**year by winter**
df	4	4	4
H	117.33	396.61	233.29
p-value	<0.001	<0.001	<0.001
trend	08 > 00, 04-05 & 07	08 > 07 > 04 > 05 & 00	08 > 07 > 00 > 04-05
	year by spring	**year by spring**	**year by spring**
df	4	4	4
H	125.32	693.65	615.76
p-value	<0.001	<0.001	<0.001
trend	07 > 00 > 04-05 & 08	07 > 08 > 04-05 & 00	07 > 08, 04-05 & 00
	year by summer	**year by summer**	**year by summer**
df	7	7	7
H	340.61	226.39	317.43
p-value	<0.001	<0.001	<0.001
trend	07 > 08 > 05 > 99-00, 02, 04 & 06	05 > 07-08 & 04 > 06, 02 & 99-00	07-08 > 99-00, 02 & 04-06
	year by fall	**year by fall**	**year by fall**
df	5	5	5
H	98.48	437.45	498.64
p-value	<0.001	<0.001	<0.001
trend	06 > 07 > 02 > 99-00 & 04	07 > 06 > 02 > 04 & 99-00	07 > 99-00, 02, 04 & 06

Appendix 1, continued

	Blue runner		Amberjack		Great barracuda
	seasons		**seasons**		**seasons**
df	3		3		3
H	1137.35		345.27		282.45
p-value	<0.001		<0.001		<0.001
trend	Jul-Sep > Apr-Jun & Oct-Dec > Jan-Mar		Jul-Sep > Apr-Mar & Oct-Dec > Jan-Mar		Oct-Dec > Jul-Sep > Apr-Jun > Jan-Mar
	year by winter		**year by winter**		**year by winter**
df	4		4		4
H	1.43		28.77		11.12
p-value	0.839		<0.001		<0.025
trend			08 > 07, 04-05 & 00		04 > 08 > 07, 05 & 00
	year by spring		**year by spring**		**year by spring**
df	4		4		4
H	24.29		218.84		102.13
p-value	<0.001		<0.001		<0.001
trend	07 > 04 > 08, 05 & 00		08 > 07 > 04-05 & 00		04 > 08 > 07, 05 & 00
	year by summer		**year by summer**		**year by summer**
df	7		7		7
H	381.42		238.22		54.17
p-value	<0.001		<0.001		<0.001
trend	99 & 05 > 06-07 > 00, 02 & 04 > 08		07 > 08, 04-06, 02 & 99-00		02 & 06 > 07-08, 04 & 99-00 > 05
	year by fall		**year by fall**		**year by fall**
df	5		5		5
H	78.42		44.64		207.83
p-value	<0.001		<0.001		<0.001
trend	02 > 06-07, 04 & 99-00		07 & 02 > 06, 04 & 99-00		04 > 06-07, 02 & 99-00

Appendix 2. PCA output for co-occurrence among 16 species/groups.

```
Eigenanalysis of the Correlation Matrix

Eigenvalue  2.3971  1.2662  1.2364  1.2134  1.1297  1.0895  0.9770  0.9557
Proportion   0.150   0.079   0.077   0.076   0.071   0.068   0.061   0.060
Cumulative   0.150   0.229   0.306   0.382   0.453   0.521   0.582   0.642

Eigenvalue  0.8791  0.8282  0.7861  0.7388  0.6888  0.6582  0.6226  0.5331
Proportion   0.055   0.052   0.049   0.046   0.043   0.041   0.039   0.033
Cumulative   0.697   0.748   0.797   0.844   0.887   0.928   0.967   1.000


Variable            PC1     PC2     PC3     PC4     PC5     PC6     PC7     PC8
sheepshead        0.056  -0.305   0.019  -0.215  -0.229   0.118   0.727  -0.225
triggerfish      -0.256   0.213  -0.120   0.264   0.056   0.439  -0.008  -0.389
blue runner       0.170   0.389  -0.381   0.075   0.192  -0.284   0.303   0.219
Shark             0.107   0.459  -0.407  -0.313  -0.153   0.044   0.086  -0.011
black sea bass   -0.313   0.189  -0.051   0.124   0.042   0.415   0.190  -0.141
spadefish        -0.330   0.073   0.075   0.265  -0.380  -0.118   0.109   0.135
scad              0.341  -0.039  -0.106   0.032  -0.238   0.284  -0.252  -0.057
tunny             0.063   0.006  -0.182  -0.365  -0.509   0.279  -0.326   0.101
tomtate           0.458  -0.047   0.171   0.151  -0.031   0.038   0.049  -0.177
snapper          -0.083   0.278   0.247  -0.196  -0.209  -0.469  -0.153  -0.349
juvenile/forage   0.347  -0.012   0.328  -0.162   0.032   0.097   0.141  -0.161
grouper          -0.087   0.413   0.515   0.100  -0.243   0.013   0.007  -0.032
cobia             0.022   0.184   0.380  -0.159   0.134   0.337   0.102   0.658
vermilion         0.308   0.024  -0.027   0.494   0.076   0.067  -0.193  -0.022
amberjacks        0.345   0.393   0.037   0.119  -0.040   0.050   0.174  -0.089
barracuda        -0.068   0.136   0.109  -0.423   0.539   0.122  -0.177  -0.277

Variable            PC9    PC10    PC11    PC12    PC13    PC14    PC15    PC16
sheepshead       -0.419  -0.074  -0.079  -0.050  -0.048   0.078   0.010  -0.112
triggerfish      -0.110   0.136  -0.122  -0.379   0.402  -0.310   0.092   0.043
blue runner      -0.004   0.073  -0.323  -0.323   0.042   0.191  -0.394   0.066
Shark            -0.056  -0.022   0.459   0.124  -0.219  -0.439   0.055  -0.087
black sea bass    0.252   0.272  -0.135   0.427  -0.419   0.254  -0.186   0.073
spadefish        -0.045  -0.280   0.224   0.292   0.403  -0.057  -0.488   0.037
scad             -0.195   0.308   0.432  -0.166   0.101   0.507  -0.222   0.050
tunny             0.060  -0.225  -0.559   0.003   0.021  -0.012  -0.095  -0.003
tomtate           0.000  -0.061  -0.064   0.103  -0.123  -0.316  -0.174   0.732
snapper          -0.279   0.498  -0.203   0.190   0.077  -0.000  -0.000   0.003
juvenile/forage   0.518   0.158   0.011  -0.043   0.184  -0.211  -0.352  -0.438
grouper          -0.001  -0.302   0.079  -0.457  -0.403   0.129   0.017  -0.040
cobia            -0.296   0.274  -0.051   0.083   0.152  -0.139   0.046   0.065
vermilion        -0.429  -0.101  -0.192   0.229  -0.232  -0.168  -0.127  -0.479
amberjacks        0.137  -0.244  -0.064   0.328   0.366   0.331   0.486  -0.013
barracuda        -0.256  -0.401   0.043   0.119   0.095   0.160  -0.306   0.041
```

Appendix 3. PCA output for daily associations between 16 species/groups and seven environmental factors.

```
Eigenanalysis of the Correlation Matrix


Eigenvalue  2.0594  1.1576  1.1335  1.0309  0.8969  0.7154  0.6587  0.3476
Proportion   0.257   0.145   0.142   0.129   0.112   0.089   0.082   0.043
Cumulative   0.257   0.402   0.544   0.673   0.785   0.874   0.957   1.000


Variable      PC1     PC2     PC3     PC4     PC5     PC6     PC7     PC8
frac       -0.035   0.248  -0.365  -0.692   0.535  -0.035  -0.186  -0.054
wax/wane    0.070   0.251  -0.688  -0.026  -0.545   0.381   0.111   0.057
photo       0.555   0.211   0.157  -0.023   0.213   0.146   0.345   0.661
temp       -0.591  -0.075  -0.088  -0.054  -0.135  -0.257  -0.163   0.724
sal        -0.385   0.288   0.311   0.113   0.188   0.767  -0.185   0.028
wave        0.155  -0.281  -0.466   0.570   0.450   0.086  -0.363   0.116
baro        0.164   0.729   0.100   0.249  -0.128  -0.353  -0.479  -0.016
mean RA    -0.372   0.363  -0.193   0.343   0.314  -0.213   0.642  -0.136
```

Appendix 4. PCA output for hourly associations between 16 species/groups and 11 environmental factors.

```
Eigenanalysis of the Correlation Matrix


Eigenvalue  2.0753  1.3162  1.2219  1.1361  1.0050  1.0035  0.9698  0.8631
Proportion   0.173   0.110   0.102   0.095   0.084   0.084   0.081   0.072
Cumulative   0.173   0.283   0.384   0.479   0.563   0.646   0.727   0.799

Eigenvalue  0.7422  0.6678  0.6651  0.3340
Proportion   0.062   0.056   0.055   0.028
Cumulative   0.861   0.917   0.972   1.000


Variable      PC1     PC2     PC3     PC4     PC5     PC6     PC7     PC8
mean RA     0.360  -0.069   0.114  -0.342   0.194  -0.104  -0.104  -0.386
tod         0.008   0.078  -0.292   0.460   0.458  -0.173  -0.534  -0.287
frac        0.038  -0.677   0.159   0.146   0.031  -0.119  -0.100   0.155
wax/wane   -0.085  -0.226  -0.163  -0.422  -0.337  -0.111  -0.696   0.098
photo      -0.550   0.066   0.238  -0.016   0.170  -0.062  -0.030  -0.078
tide el    -0.011  -0.054   0.052   0.004   0.091   0.958  -0.236  -0.071
tide rng    0.083   0.652  -0.144  -0.146  -0.110  -0.036  -0.216   0.223
tide stg    0.065  -0.053  -0.096  -0.451   0.733  -0.001   0.073   0.448
wtmp        0.588  -0.041  -0.011  -0.039  -0.179   0.039   0.024   0.105
salin       0.375   0.123   0.387   0.043   0.139  -0.048  -0.056  -0.332
wave       -0.150  -0.115  -0.479  -0.393  -0.024   0.034   0.276  -0.573
baro       -0.194   0.120   0.617  -0.299  -0.009  -0.070  -0.148  -0.155

Variable      PC9    PC10    PC11    PC12
mean RA     0.718  -0.020   0.058  -0.086
tod        -0.124  -0.120   0.230   0.083
frac       -0.016   0.594   0.285  -0.104
wax/wane   -0.100  -0.101  -0.308   0.041
photo       0.238   0.259  -0.194   0.659
tide el     0.034   0.071   0.039  -0.003
tide rng    0.074   0.589   0.235  -0.096
tide stg   -0.178  -0.044  -0.059   0.015
wtmp       -0.139  -0.079   0.254   0.718
salin      -0.402   0.304  -0.547  -0.056
wave       -0.301   0.236   0.157   0.067
baro       -0.303  -0.218   0.530  -0.082
```

Appendix 5. Results of K-W rank and Dunn's testing for time of day and tidal differences.

Species or Group	Parameter	Tide stage	Tide range	% of tide elapsed	Time of day
Black sea bass	df	1	3	3	3
	H	0	7.2	3.81	13.84
	p-value	0.998	0.066	0.283	**0.003***
	trend				least 16:00-18:00
Gray triggerfish	df	1	3	3	3
	H	1.31	3.34	4.22	1.76
	p-value	0.252	0.342	0.239	0.623
	trend				
Atlantic spadefish	df	1	3	3	3
	H	9.55	38.79	3.28	4.81
	p-value	**0.002***	**<0.001***	0.35	0.186
	trend	slightly > flood	greatest at extremes		
Sheepshead	df	1	3	3	3
	H	0.23	4.55	2.56	29.1
	p-value	0.628	0.208	0.465	**<0.001***
	trend				greatest >12:00
Snapper	df	1	3	3	3
	H	0.24	0.47	8.65	2.22
	p-value	0.623	0.926	**0.034***	0.539
	trend			*least 50.1-75%*	
Grouper	df	1	3	3	3
	H	0.94	2.9	7.06	48.09
	p-value	0.332	0.407	0.07	**<0.001***
	trend				gradient (most early, least late)
Tomtate	df	1	3	3	3
	H	38.38	4.09	20.82	7.85
	p-value	**<0.001***	0.252	**<0.001***	**0.049***
	trend	flood > ebb		least 50.1-75%	greatest 10:00-12:00 and 16:00-18:00
Vermilion snapper	df	1	3	3	3
	H	32.44	9.75	1.54	2.12
	p-value	**<0.001***	**0.021***	0.673	0.547
	trend	flood > ebb	greatest 1.6-2.0m		

Appendix 5, continued

Species or Group	Parameter	Tide stage		Tide range		% of tide elapsed		Time of day
Mixed forage/juvenile	df	1		3		3		3
	H	4.84		26.07		3.91		9.01
	p-value	**0.028**		**<0.001***		0.271		**0.029***
	trend	flood > ebb		greatest 1.1 to 2.0 m				slightly greater 10:00-12:00 hrs
Scad	df	1		3		3		3
	H	6.81		6.77		4.46		10.14
	p-value	**0.009***		0.08		0.216		**0.017***
	trend	flood > ebb						least 07:00-09:00 hrs
Blue runner	df	1		3		3		3
	H	0.6		16.78		10.76		7.18
	p-value	0.432		**0.001***		**0.013***		0.066
	trend			least >2m		least 50.1-75%		
Amerberjacks	df	1		3		3		3
	H	30.68		4.04		18.3		8.03
	p-value	**<0.001***		0.257		**<0.001***		**0.045***
	trend	flood > ebb				greatest 0-50%		greatest 07:00-09:00
Great barracuda	df	1		3		3		3
	H	24.03		5.72		3.8		3.27
	p-value	**<0.001***		0.126		0.284		0.351
	trend	flood > ebb						
Little tunny	df	1		3		3		3
	H	1.21		6.5		1.14		20.64
	p-value	0.271		0.09		0.768		**<0.001***
	trend							greatest >12:00
Cobia	df	1		3		3		3
	H	3.22		1.27		0.61		2.38
	p-value	0.073		0.737		0.894		0.497
	trend							
Requiem sharks	df	1		3		3		3
	H	4		0.61		3.19		4
	p-value	**0.045***		0.895		0.363		0.262
	trend	flood > ebb						

Appendix 6. Results of K-W rank and Dunn's testing for lunar differences.

Species or Group	Parameter	Moon Fraction		Moon Phase (wax, wane)
Black sea bass	N obs (days)	403		403
	df	3		1
	H	2.04		0.3
	p-value	0.528		0.584
	trend			
Gray triggerfish	N obs (days)	194		194
	df	3		1
	H	0.03		0.25
	p-value	0.934		0.618
	trend			
Atlantic spadefish	N obs (days)	484		484
	df	3		1
	H	2.76		0.37
	p-value	0.43		0.542
	trend			
Sheepshead	N obs (days)	41		41
	df	3		1
	H	3.2		0
	p-value	0.362		0.989
	trend			
Snapper	N obs (days)	122		122
	df	3		1
	H	6.4		0.03
	p-value	0.094		0.864
	trend			
Grouper	N obs (days)	498		498
	df	3		1
	H	0.35		5.37
	p-value	0.951		**0.021***
	trend			wax > wane
Tomtate	N obs (days)	607		607
	df	3		1
	H	3.68		0.27
	p-value	0.298		0.603
	trend			
Vermilion snapper	N obs (days)	368		368
	df	3		1
	H	5.28		1.54
	p-value	0.153		0.215
	trend			

Species or Group	Parameter	Moon Fraction		Moon Phase (wax, wane)
Mixed forage/juveniles	N obs (days)	662		662
	df	3		1
	H	0.14		0.08
	p-value	0.986		0.771
	trend			
Scad	N obs (days)	453		453
	df	3		1
	H	2.87		2.34
	p-value	0.412		0.126
	trend			
Blue runner	N obs (days)	186		186
	df	3		1
	H	4.62		0.11
	p-value	0.202		0.74
	trend			
Amberjacks	N obs (days)	287		287
	df	3		1
	H	3.78		0.05
	p-value	0.286		0.829
	trend			
Great barracuda	N obs (days)	255		255
	df	3		1
	H	4.23		2.63
	p-value	0.238		0.105
	trend			
Little tunny	N obs (days)	59		59
	df	3		1
	H	9.99		0.41
	p-value	**0.019***		0.524
	trend	*greatest 0-25%*		
Cobia	N obs (days)	46		46
	df	3		1
	H	2.54		0.5
	p-value	0.468		0.481
	trend			
Requiem sharks	N obs (days)	54		54
	df	3		1
	H	3.4		0.99
	p-value	0.333		0.319
	trend			

Appendix 7. Summary (as of 2007) of tag-recapture data available for selected benthic game fishes in the SAB.

Species	Acoustic telemetry data?	*n* tagged	*n* recaptured	% recaptured	Mean Duration At-Large	movement >10 km *n* fish (%)
Atlantic spadefish	no					
MARMAP*		1	0	0.0		
MGFTP+		1065	48	4.5	3 mo.	0
ALS-NMFS NE#		3	0	0.0		
Scamp	no					
MARMAP		160	13	8.1		
MGFTP		1401	73	5.2	5 mo.	18 (2.5%)
NMFS^		34	7	20.6		
ALS-NMFS NE		3	0	0.0		
Red snapper	yes (GOM)					
MARMAP		45	2	4.4		
MGFTP		1597	176	11.0	8 mo.	35 (19.8%)
NMFS^		168	17	10.1		
ALS-NMFS NE		3	0	0.0		
Gray triggerfish	no					
MARMAP		837	52	6.2		
MGFTP		66	12	18.2	2 mo.	0
NMFS^		7	1	14.3		
ALS-NMFS NE		49	4	8.2		
Gag	yes (GOM)					
MARMAP		3776	477	12.6		
MGFTP		1503	162	10.8	6 mo.	35 (21.6%)
NMFS^		168	22	13.1		
ALS-NMFS NE		68	9	13.2		
Black sea bass	yes (Mid-Atlantic)					
MARMAP		17140	3743	21.8		
MGFTP		1177	120	10.2	1.5 mo.	2 (1.6%)
ALS-NMFS NE		94	3	3.2		

*MARMAP Tagging Database (contact Jessica Stephen, 843-953-9827)
+MGFTP Tagging Database (contact Robert Wiggers, 843-953-9363)
^NMFS Cooperative Game Fish Tagging Program (contact Eric Orbesen, 1-800-437-3936)
#American Littoral Society (contact Gary Shepherd, NMFS; gshepher@whsun1.wh.whoi.edu)

Note:
(a) North Carolina does not appear to have a fishery-dependent or fishery-independent tagging program for species in Table 1
(b) GA Cooperative Tagging Program does not target species in Table 1; Contact Donna McDowell (912-266-1234)
(c) FLDEP (angler- and research-based efforts) does not target species in Table 1; Contact Wendy Quigley (727-896-2058)

Source: Cooperative Tagging WebSite and Registry, http://fwie.fw.vt.edu/TAGGING/