BULLETIN OF MARINE SCIENCE, 80(3): 587–594, 2007

NOTE

ACTIVITY PATTERNS OF THREE JUVENILE GOLIATH GROUPER, *EPINEPHELUS ITAJARA*, IN A MANGROVE NURSERY

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Goliath grouper, *Epinephelus itajara* (Lichtenstein, 1822), was a protected species historically distributed throughout tropical and subtropical coastal waters of the western and eastern Atlantic Ocean. It also occurs at similar latitudes in eastern Pacific coastal waters (Heemstra and Randall, 1993). The species—listed as critically endangered by the World Conservation Union (Hudson and Mace, 1996)—has been protected through a total fishing ban in U.S. federal and state waters since 1990 (Sadovy and Eklund, 1999) and in Puerto Rico and U.S. Virgin Islands waters since 2004 (NMFS, 2006). As one of the few grouper species that shows a high affinity for mangrove-dominated areas, *E. itajara* typically spends its first 5–8 yrs in that nearshore habitat before migrating to adult habitats (i.e., coral reefs, rock ledges, isolated patch reefs, and artificial structures) (Sadovy and Eklund, 1999). Visual underwater surveys in the Florida Keys reveal that juvenile *E. itajara* prefer well-developed fringing red mangrove *Rhizophora mangle* Linnaeus shorelines with high structural complexity (undercuts, extensive overhangs) and soft sediment (Frias-Torres, 2006). To date, knowledge of the movement of goliath grouper juveniles within their mangrove nursery areas is based mainly on conventional tagging studies. However, these have provided only limited insight into the fine-scale activity patterns, especially those occurring on a daily or subdaily basis (Eklund and Schull, 2001).

In the present study, we used electronic acoustic tags and stationary hydrophone receiver stations to examine the activity patterns of three tagged juveniles inhabiting the fringing red mangrove shorelines of Ten Thousand Islands, southwest Florida, U.S. (Fig. 1). Bullock and Smith (1991) described this region as the historical center of abundance for *E. itajara* in U.S. waters. Our primary objective was to examine the extent to which juvenile activity was associated with time of day and tidal stage. Previous investigations demonstrated a high degree of juvenile site fidelity as well as resilience to, and rapid recovery after, handling (Eklund and Schull, 2001). To test our ability to detect movement at fine timescales over periods of weeks to months, as well as cues for fish movement, we examined the relationship between fish presence-absence, tidal cycle, and time of day in juvenile goliath grouper. Our results provide insight into multiple habitat use by this species and are important to consider when designing and implementing population abundance surveys.

Methods

In October 2000, three goliath grouper (Table 1) were captured and tagged with acoustic transmitters in Rabbit Key Pass (25°78´N, 81°36´W), Ten Thousand Islands, southwest Florida (Fig. 1). Temperature ranged from 18 to 31.7 °C, salinity from 1.8 to 40.6, dissolved oxygen from 2.4 to 7.7 mg L^{-1}, water depth from 2 to 10 m, and tidal amplitudes ranged up to 2 m (Eklund and Schull, 2001; SFWMD, 2006). Acoustic transmitters (VEMCO®, 16 mm diameter,

Table 1. Juvenile goliath grouper size, capture, and acoustic monitoring details. Abbreviations: ID = fish identification number; TL = total length.

ID	Capture date	TL (mm) at capture	Capture site	Dataset: start date	Dataset: end date	Days of data
11	October 5, 2000	410	1	December 12, 2000	August 27, 2002	615
30	October 4, 2000	660	1	December 12, 2000	December 31, 2000	20
31	October 4, 2000	840	2	December 12, 2000	August 7, 2001	237

92 mm long, 16 g in water) were implanted within the intraperitoneal cavity; each tag emitted a unique signal every 2 min at 69 kHz. Manufacturer specifications estimate a battery life of 643 d. Two Vemco VR1 data-logging acoustic receivers were moored within 20 m of each capture location. Range tests demonstrated an approximate 100 m radius range for each receiver, and there was overlap between both receivers' range (Fig. 1). A prior conventional tagging and manual tracking experiment (Eklund and Schull, 2001) revealed that juveniles at this study site were frequently recaptured at their original tagging locations, and therefore, would be readily detected by the receivers.

Initially, we attached additional pingers to each receiver for equipment relocation purposes, but later documented interference between relocation pingers and acoustic fish tags. We subsequently removed the relocation pingers in December 2000, accounting for the gap between capture dates and dataset start dates.

Due to non-normality and lack of independence of errors (i.e., autocorrelation), variation in fish detection in relation to tidal stage and time of day was examined using a nonparametric analysis of variance equivalent as well as spectrum (Fourier) analysis. In the former, Scheirer-Ray-Hare extension of the Kruskal-Wallis tests (followed by Mann-Whitney U-tests for post-hoc comparisons) were used (Sokal and Rohlf, 1995) whereby the dependent variable was the proportion of (positive) fish detections (of 32 possible per hour) and the independent variables were tidal stage (four levels), time-of-day (four levels), and the interaction term. The four tidal stages were low, high, flood, and ebb; the former stages were defined as 2-hr periods of least tidal flow. The four times of day were day, night, dawn, and dusk; the latter were defined as 3-hr intervals beginning 1.5 hrs before and ending 1.5 hrs after sunrise or sunset, respectively. Samples sizes for each case and fish are shown in Table 2. To reveal cyclical components of each fish detection time series, single spectrum analyses using the fast Fourier transform

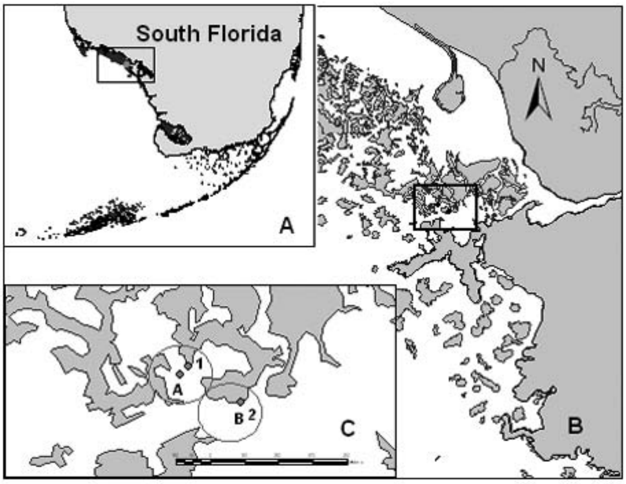

Figure 1. Map of study area: (A) southern Florida, USA; (B) Ten Thousand Islands; and (C) Rabbit Key Pass. Shown are fish capture sites (1 and 2), and hydrophone receiver locations (A and B).

Table 2. Sample sizes (number of hourly presence proportions) for each data point in Figure 2 and used in the nonparametric analyses of variance (Scheirer-Ray-Hare extension of the Kruskal-Wallis test) as well as post hoc mean comparisons (Mann Whitney U-tests). Times of day indicated as dawn, day, dusk, and night.

Tide	Low	Flood	High	Ebb
Fish 11				
Dawn	155	264	215	614
Day	656	1,151	577	1,328
Dusk	137	250	243	621
Night	662	1,057	575	1,495
Fish 30				
Dawn	6	8	4	39
Day	28	49	15	41
Dusk	6	14	17	20
Night	34	54	38	84
Fish 31				
Dawn	90	172	126	326
Day	391	714	381	748
Dusk	79	115	134	386
Night	358	558	279	849

were performed. These results were examined via periodograms (i.e., plots of spectral density vs period).

RESULTS

Tagged fish measured 410–840 mm total length (TL) and were detected for 20–615 d after interfering pingers were removed from the listening stations (Table 1). For the longest detected fish (fish 11), signs of tag failure were evident during the last 32% of its record. Specifically, near linear reduction in detections began on day 416 and continued thereafter. Therefore, data after day 416 were omitted from analyses.

Over the entire sampling period, fish 11 was only detected at hydrophone A (capture site 1); fish 30 was also detected at hydrophone A, and for 20 hrs at hydrophone B; fish 31 was detected at hydrophone B (capture site 2), and for 5 hrs at hydrophone A. Although cross-detections were rare, overall the data indicate that hydrophone locations resulted in range detection overlap, and were appropriate to detect fish movement within the site. Most absences were < 24 hrs, and the majority of movements out of the receiver's range were within 12 hrs (98% for fish 11, 89% in fish 30, and 70% in fish 31).

For all three fish, the time of day × tide interaction terms were highly significant (Table 3). While activity levels differed by fish and time of day, for the most part, activity patterns were similar in that the highest proportion of detections occurred during the low and ebb tidal stages and the lowest during flood and high tides (Fig. 2). Spectrum analysis tended to corroborate that fish activity was synchronized with the tidal cycle. For all three fish, spectral density peaks were evident at 12 and 24 hr periods, which roughly correspond to the semidiurnal and diurnal tidal periods (Fig. 3).

Table 3. Results of nonparametric analyses of variance (i.e., Scheirer-Ray-Hare tests) whereby the proportion of positive fish detections (presence) was the dependent variable and time of day (TOD) and tidal stage (Tide) were the independent variables. Critical $\chi^2_{9,\,0.05} = 16.919$.

Source	SS	SS/MS$_{total}$	df	P
Fish 11				
TOD	217,221,944.8	26.51291	3	< 0.001
Tide	9,767,117,728	1,192.12	3	< 0.001
TOD × Tide	804,418,809.5	98.1829	9	< 0.001
Fish 30				
TOD	176,345.468	10.26977	3	0.0164
Tide	446,900.487	26.02599	3	< 0.001
TOD × Tide	414,874.14	24.16088	9	0.004
Fish 31				
TOD	299,571,114.9	168.3022	3	< 0.001
Tide	158,628,691.2	89.11924	3	< 0.001
TOD × Tide	83,915,063.55	47.14435	9	< 0.001

Discussion

Site Fidelity.—Juvenile goliath grouper showed high site-fidelity. Absence appeared size-related, with the longest absence periods in the largest of the three fish (fish 31, 840 mm TL at capture). The relation between longer absences and increased fish size may be due to higher metabolic demands which require greater time foraging, in concert with a reduction in vulnerability to predators (Levin and Grimes, 2002). Several grouper species show site-fidelity as juveniles (*Mycteroperca microlepis* (Goode and Bean, 1879) Koenig and Coleman, 1998; *Epinephelus marginatus* (Lowe, 1834) Lembo et al., 1999; *E. itajara* and *Epinephelus striatus* (Bloch, 1792) Sadovy and Eklund, 1999). Low water levels may limit fish movements. At low tide juvenile goliath grouper may be restricted to deeper sites, such as eroded ledges under the mangroves (undercuts) or other deep microhabitats until the next tidal rise. In this study, the sites where the fish were monitored had deep undercuts and soft sediment, a preferred habitat for juvenile *E. itajara* (Frias-Torres, 2006). If a juvenile fails to return before low tide, it may effectively be separated from its refuge.

Fish 11, the smallest of the three fish, was detected for almost 2 yrs, although transmitter interference and apparent malfunction reduced the time series to about 13.5 mo. The signal from fish 30 barely lasted one month after the start date of data collection. Whether its acoustic tag failed, the fish moved to a different location, or it was lost due to predation or removal is unknown. The signal from fish 31 lasted 10 mo after capture and yielded 7 mo of useful data. As the largest of the fish, it is possible that the lack of detection of fish 31 later in the study reflected the onset of the ontogenetic migration. Goliath grouper show ontogenetic habitat migrations and move from the nursery mangrove habitat to the adult habitat (reefs, rock ledges, coral reefs) as they reach sexual maturity, within the 1100–1200 mm TL range (Sadovy and Eklund, 1999; Eklund and Schull, 2001). Assuming fish 31 was growing normally, it would have attained about 1000 mm TL by the end of its detection record (Bullock et al., 1992).

Daylight/Tidal Phase.—Both the Scheirer-Ray-Hare tests and spectrum analyses suggested fish activity was correlated mainly with tidal cycle with a tendency to

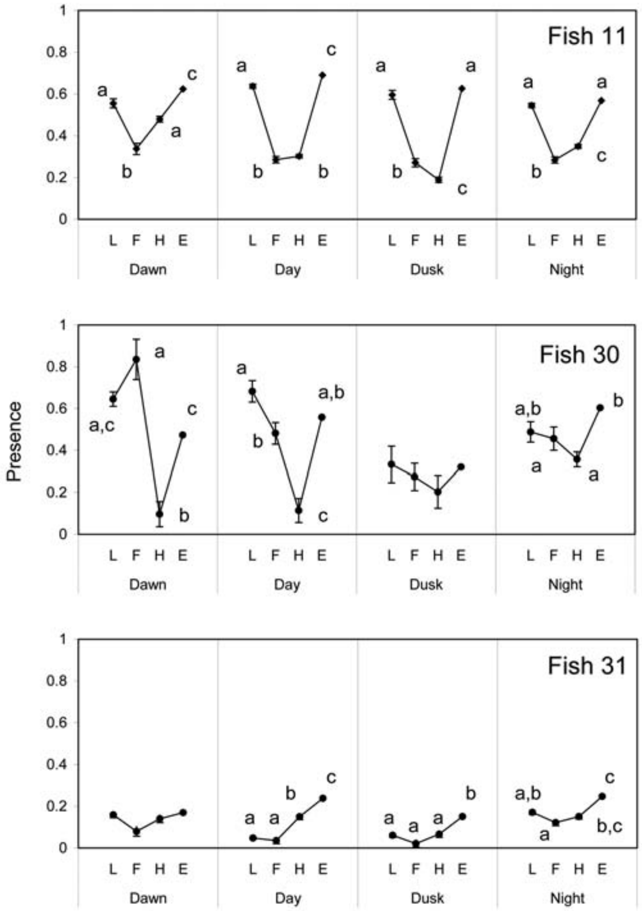

Figure 2. Presence (mean ± SE) of tagged juvenile *Epinephelus itajara* juveniles for each time of day and tidal stage in mangrove habitats of Rabbit Key Pass. Means sharing the same lower case letters are not statistically different (P > 0.05); panels without letters contain means that are not significantly different. Abbreviations: L = low tide, F = flood tide, H = high tide, E = ebb tide.

move out of the receiver's range on flood and high tides, and remain within range on ebb and low tides. While there were a few exceptions to this general pattern, its consistency suggests high and increasing water levels prompt fish movement regardless of time-of-day. Without a larger array of receivers, we cannot determine where juveniles go during their tidal excursions. Juvenile gag (*M. microlepis*), another grouper species that utilizes estuarine habitats as nursery, appears to forage in seagrass meadows at high tide (Ross and Moser, 1995) and use 2-m deep channels that meander through the much shallower marsh-seagrass landscape when the tide ebbs. Twilight (dusk) migrations also occur in mangrove habitats for a variety of families, such as Haemulidae, Lutjanidae, Acanthuridae, Scaridae, Chaetodontidae, and Pomacentridae (Rooker and Dennis, 1991; Nagelkerken et al., 2000).

Although fish movement was correlated with tide, in this study we could not ascertain what type of activity was associated with such movement, but foraging seems likely. Excursions during high water levels allow for expanded exploration of foraging

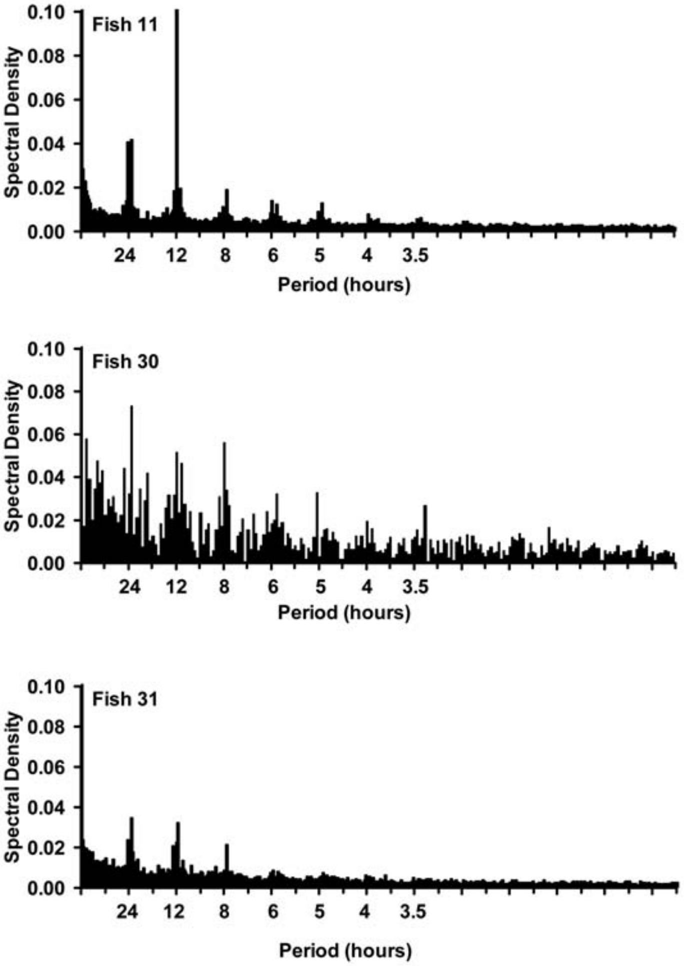

Figure 3. Juvenile *Epinephelus itajara* activity and tidal cycle. Plots of spectral density vs period (periodograms) based on spectrum analyses using the fast Fourier transform.

grounds, including those otherwise too shallow to access. Potthoff and Allen (2003) found that pinfish [*Lagodon rhomboides* (Linnaeus, 1766)] which expanded their foraging range with rising water levels consumed more shrimp than those that did not. Crustaceans, mostly shrimps and xanthid crabs (Odum, 1971; Bullock and Smith, 1991) are important in the diet of juvenile goliath grouper. Several observations support the hypothesis that juvenile goliath grouper might move during flood and high tides for foraging purposes. Odum et al. (1982), proposed that juvenile goliath grouper invaded tidal streams primarily to feed. During underwater visual surveys in the mangroves of the Florida Keys, juvenile goliath grouper were found hovering over the bottom at sites recently flooded by high tides (Frias-Torres, 2006).

In conclusion, we provide empirical evidence suggesting that short-term movement patterns of three juvenile *E. itajara* were strongly related to tide. Future population monitoring of juvenile *E. itajara* abundance in natural mangrove habitats should take into consideration the movement patterns indicated here, and adjust sampling efforts (e.g., among shoreline and non-shoreline habitats) accordingly. Comparing stomach contents of juvenile *E. itajara* using non-lethal methods (Eklund and Schull, 2001), at various tidal stages, might provide further evidence of foraging activity during tidal migrations.

Acknowledgments

We thank J. A. Bohnsack, C. Koenig, and two anonymous reviewers who provided comments that improved the manuscript; and T. Bevis, J. Contillo, L. Demere, C. Koenig, D. McClellan, J. White, and B. White who helped in fieldwork and data logistics. Thanks also to J. Luo for help with statistics. This study was funded by a National Research Council Postdoctoral Fellowship to SFT, a European Union Scholarship to PB, the Office of Protected Resources, and the Marine Fisheries Initiative from the Southeast Fisheries Science Center, National Oceanic and Atmospheric Administration. The National Marine Fisheries Service, National Oceanic and Atmospheric Administration does not endorse any proprietary product mentioned here.

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