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research paper

Residency and fine-scale habitat use of juvenile goliath grouper (*Epinephelus itajara*) in a mangrove nursery

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ABSTRACT.—The Atlantic goliath grouper (*Epinephelus itajara*) is the largest grouper species in the Atlantic and exhibits high site fidelity and limited range of movement. By 1990, the goliath grouper population in US waters had declined approximately 95% relative to unfished levels, leading to a harvest ban in 1990. Since then, the south Florida population has grown but the magnitude of recovery remains unknown due to uncertainties about life history characteristics. However, despite these unknowns, the state of Florida approved a limited recreational harvest of goliath grouper. In 2021, fine-scale habitat use of three juvenile goliath grouper was investigated using acoustic telemetry and a positioning solver. All three individuals exhibited high site fidelity as well as a diel habitat use pattern, utilizing seagrass habitat during the night and mangrove habitat during the day. Fine-scale acoustic telemetry provides insight into not only habitat use, but broader habitat preferences as well. This study illustrates the need to consider deep seagrass-dominated channels lined with red mangroves when protecting juvenile goliath grouper populations within Florida Bay, especially as the population is opened to harvest.

The Atlantic goliath grouper (*Epinephelus itajara*) is a large, charismatic grouper species occurring in subtropical and tropical waters of the Atlantic Ocean. As the largest grouper species in the Atlantic, goliath grouper can grow up to 2.4 m in length and weigh 310 kg (Robins and Ray 1986, Koenig et al. 2020). Goliath grouper have long life spans (at least up to 37 yrs), late sexual maturity, and undergo an ontogenetic shift from inshore estuarine habitats (primarily mangroves) to near and offshore reefs as adults (Koenig et al. 2007, 2017). Throughout their life cycle, goliath

grouper exhibit high site fidelity and limited range of movement with the exception of spawning-related migrations in late summer (Frias-Torres et al. 2007, Koenig et al. 2007, 2017, Collins 2014, Ellis et al. 2014). In south Florida, juveniles are found in high abundance along the coast within the Ten Thousand Islands and Everglades National Park, with lower densities found in Florida Bay (Frias-Torres et al. 2007, Koenig et al. 2007). While utilizing the inshore habitat, goliath grouper settle in estuaries and then makes use of structure within mangrove trees (undercuts, prop roots, etc.) as shelter (Koenig et al. 2007, Lara et al. 2009, Shideler et al. 2015).

These characteristics leave goliath grouper highly susceptible to overfishing. By 1990, the goliath grouper population in US waters had declined approximately 95% relative to unfished levels (McClenachan 2009, SEDAR 2016). In response to this dramatic fishery-induced decline, managers prohibited harvest of goliath grouper in 1990; subsequently, the species was added to the IUCN critically endangered list in 1994 (Groombridge 1993, McClenachan 2009, Koenig et al. 2011). Following the harvest closure, the south Florida population of goliath grouper has grown relative to 1990; however, the magnitude of recovery remains unknown (Cass-Calay and Schmidt 2009, Koenig et al. 2011, Bertoncini et al. 2018).

There is currently a lack of understanding of the fine-scale movement of juveniles within their estuarine nursery habitats (Koenig et al. 2020). Previous studies have investigated habitat selection (Koenig et al. 2007, Lara et al. 2009) and daily movement (Frias-Torres et al. 2007) of juvenile grouper within the Ten Thousand Islands region at a broad scale. These studies concluded that red mangrove habitats are the primary habitat for juvenile goliath grouper and daily movement is related to tide. However, no information exists on specific daily habitat use and movement patterns of juveniles within Florida Bay, which is crucial for understanding site selection and fidelity of juvenile goliath grouper as well as their susceptibility to harvest. Here, we investigated the fine-scale movement of three juvenile goliath grouper in a deep seagrass-dominated channel lined with red mangroves in Florida Bay by asking "What is the fine-scale diel habitat use of juvenile goliath grouper within a mangrove nursery habitat?" We hypothesized that, similar to previous research, juvenile grouper would exhibit high site fidelity and a preference for structured habitat by exhibiting higher residency in structured habitats compared to other habitats within the study area.

Materials and Methods

Movement of juvenile goliath grouper was investigated in a mangrove channel located in Central Florida Bay, Everglades National Park (Fig. 1A). This location consisted of two mangrove-lined banks with seagrass habitat in the middle of the channel at a depth of 3–4 m. We observed the presence of juvenile grouper in this location while conducting visual underwater surveys via snorkel during site selection (Fig. 1B) and then established an array of seven acoustic receivers consisting of Innovasea VR2W (n = 5) and VR2Tx (n = 2) receivers with overlapping detection ranges (approximately 100 m, listening capability within the channel not affected by tide due to depth of channel) in June of 2021 to track goliath grouper movement (Fig. 1A). The average depth of each receiver was 2 m (range = 1.5–2.5 m). Habitats were hand-delineated using aerial imagery of the channel, categorizing mangrove and seagrass habitats (Fig. 1A). The array was removed in December 2021, providing a duration of 187 possible days where tagged fish could be detected.

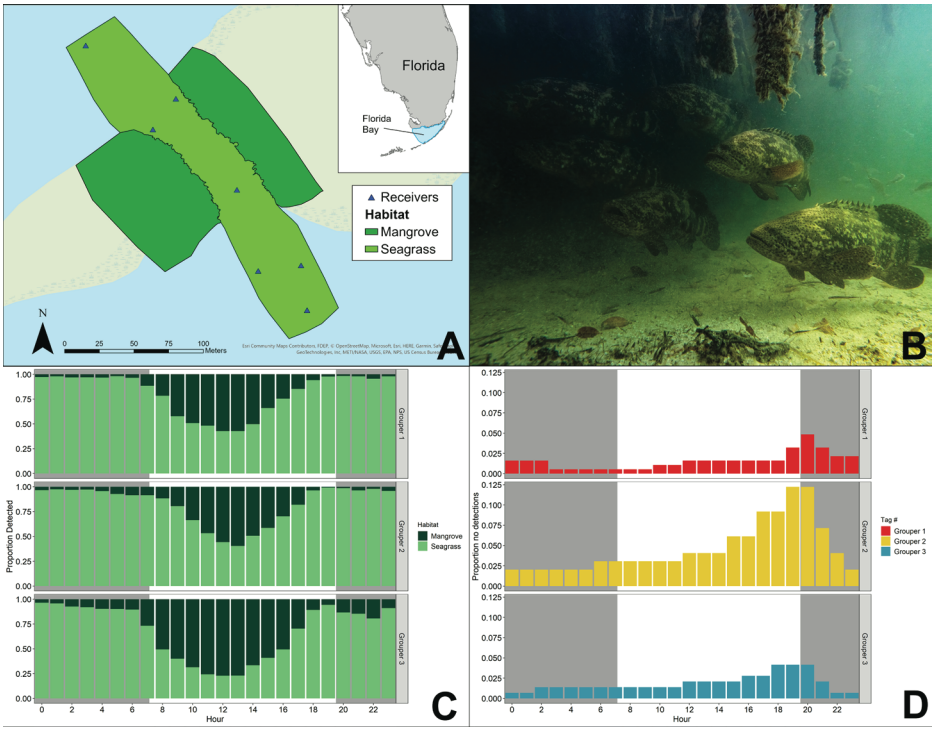

Figure 1. Study area and summary of results. (A) Mangrove channel study area in Florida Bay, Everglades National Park. Acoustic receiver locations are indicated by the blue triangles. Delineation of seagrass and mangrove habitat are indicated by the light and dark green areas, respectively. Detection range of acoustic receivers is 100 m. Array was monitoring from June through December 2021. (B) Photo illustrating the abundance of juvenile goliath grouper in the study area (Photo credit: Ian Wilson). (C) Average proportion of positions within seagrass and mangrove habitats for each 1-hr time bin across 24 hrs. A white background indicates daytime, and a grey background indicates nighttime. (D) Average proportion of possible detections missing within each 1-hr time bin across 24 hrs.

Three goliath grouper were tagged with internal acoustic transmitters (Innovasea V9-2H, 60–90 s, 69 KHz, 9 × 24 mm, 2 g) in the fall and summer of 2021. Fish were caught with rod and reel, weighed in the landing net, and then were placed upside down in a tagging tub with fresh seawater. Length and girth measurements were made and then a small incision was made in the ventral body wall. The acoustic tag was inserted into the body cavity and then the incision was stitched closed. The fish was then monitored for 5 min off the side of the boat to allow for recovery. The first grouper was tagged in January 2021 (Grouper 1: 72 cm TL) and the other two groupers (Grouper 2: 98 cm TL, Grouper 3: 92 cm TL) were tagged in June and July 2021, respectively (Table 1).

Tracks of juvenile goliath grouper were estimated using YAPS (Yet Another Positioning Solver; Baktoft et al. 2017). YAPS is a transparent and flexible positioning solver that utilizes time of arrival data as input to maximum-likelihood state-space models that estimate positions and tracks of tagged animals. It offers better accuracy and error control over traditional positioning methods and can be run on a local computer utilizing the open-source yaps package in R (Baktoft et al. 2017, Vergeynst et al. 2020). Once positions were estimated, we filtered out positions with a

Table 1. Summary of tagged juvenile goliath grouper.

Fish ID	Weight (kg)	TL (cm)	Tagging Date	Last Detection Date	# of Positions	Proportion Seagrass	Proportion Mangroves
Grouper 1	7.64	72	1/16/2021	N/A	41,901	0.81	0.19
Grouper 2	14.6	98	6/24/2021	9/30/2021	34,381	0.83	0.17
Grouper 3	14.75	92	7/19/2021	N/A	42,387	0.73	0.27

standard deviation of more than 3 m (removed 340,874 out of 460,063 positions) and calculated the average proportion of positions within mangrove vs seagrass habitat for each 1-hr time bin across 24 hrs. These were then averaged across all detection days for each fish (*see* Table 1). Tidal influence of habitat use was also investigated in a similar manner. If a position was calculated within an hour of high or low tide (± 30 min, "tide window"), it was assigned to the corresponding tide. If a position was calculated outside of a tide window, it was considered a rising tide if the previous tide window was a low tide or a falling tide if the previous tide window was a high tide. We then calculated the average proportion of positions within mangrove vs seagrass habitat for each tidal delineation and averaged them across all detection days for each fish. We also calculated the proportion of possible detections that were missing within each 1-hr time bin across 24 hrs, which would represent a movement outside the receiver array.

Results

Two of the tagged fish, Grouper 1 and Grouper 3, were consistently detected from tagging date (or date of array establishment) through the end of the study (Table 1), generating 41,901 and 42,387 positions with less than a 3 m standard deviation, respectively. The third tagged fish, Grouper 2, was consistently detected from the date of tagging (24 June 2021) through 30 September, 2021, when it left the array and has not been detected again (34,381 positions; Table 1). Contrary to our expectations, all three tagged grouper were positioned in the seagrass habitat in the middle of the channel more than the mangrove habitat with some individual variation (Table 1). This habitat use pattern did not differ across a tidal cycle; however, this habitat use pattern differed across the 24-hr diel cycle (Online Fig. S1). All three individuals almost exclusively utilized the seagrass habitat during nighttime hours (0–6 hrs, 18–24 hrs; Fig. 1C). However, the tagged fish retreated into the mangroves during daylight hours (6–18 hrs), exhibiting a peak in mangrove usage around midday (Fig. 1C). All three tagged grouper were also highly resident within the array; we detected over 95% of possible detections for Grouper 1 and Grouper 3, while Grouper 2 utilized surrounding areas more than the other two fish during the evening (87.5%; Fig. 1D).

Discussion

In this study, we identified an area of juvenile goliath grouper presence within an area (Florida Bay) previously thought to hold few individuals due to a degraded ecosystem state (Koenig et al. 2007, Cass-Calay and Schmidt 2009). Grouper within this area exhibited high site fidelity throughout the tracking period, which is consistent with previous findings from other areas (Frias-Torres et al. 2007, Koenig et al. 2007, Lara et al. 2009, Shideler et al. 2015). Two of the three tagged individuals

left the channel less than 5% of the time, thus we infer that all activities, including both resting and foraging, occurred within the channel. The third tagged individual spent more time outside of the channel array than the other two (Grouper 2: 12.5% at most), exited the system completely in late September, and was not detected in the array again. This individual was the largest of the three tagged groupers at 98 cm TL (Table 1), and its size corresponds to the age at which goliath grouper have been shown to migrate to adult habitats (Brusher and Schull 2009). Therefore, we suspect that the higher rate of missed detections resulted from the individual leaving the channel to explore surrounding habitats in preparation to make an ontogenetic shift.

All three tagged individuals exhibited a distinct diel pattern of habitat use and movement in which they were positioned under mangroves during the day and moved around the seagrass habitat at night. This pattern has been documented before in other reef species utilizing inshore habitats as juveniles (grey snapper *Lutjanus griseus*, Luo et al. 2009; bluestriped grunt *Haemulon sciurus*, Hammerschlag and Serafy 2010; sea bream *Archosargus rhomboidalis*, Hammerschlag and Serafy 2010). However, this is the first observation of such movements by goliath grouper. Previous research linked juvenile goliath grouper movement forays with tidal cycles, where individuals utilized more seagrass and open habitat at rising and high tides, then moved back to shelter during falling and low tides (Frias-Torres et al. 2007). In fact, we found that tide was not a factor in habitat use by juvenile grouper (Online Fig. S1). The switch from a tidally-driven to a time-driven movement pattern is likely due to the depth of the habitats investigated in this study. The average depth of the channel containing both seagrass and mangrove habitat was 3 m, providing access to both habitats at all times. Therefore, instead of waiting for high tide to forage on flats around the mangrove shelter areas, the grouper in this channel can utilize the seagrass to forage at night and use the mangroves during the day as a temperature and predation refuge (Hendy et al. 2020).

The use of fine-scale acoustic telemetry in this study not only elucidated habitat usage within the channel habitat but provided insight into possible broader habitat preferences of large juvenile goliath grouper within the Florida Bay region. Fine-scale movement studies are crucial to provide insight into the mechanisms of broader movement and habitat selection of managed species (Nathan et al. 2022). Through this study we found that the high residency and differences in diel movement patterns within the channel suggest that deep channels dominated by tall seagrass and lined with red mangroves may be an ideal habitat for juvenile goliath grouper. Therefore, as the population is opened to harvest, protecting these specific habitats may help to preserve juvenile goliath grouper populations. The proposed harvest slot includes these large juvenile fish, and the high residency shown here can be easily exploited by anglers seeking out habitats that will likely host a high abundance of slot-sized fish. However, due to the limited sample size (3 fish) and few habitat features (a single deep seagrass-dominated channel lined with red mangroves) in this study as well as a lack of knowledge on how these ecosystems will respond to the removal of large juveniles, more information is needed on juvenile goliath grouper spatial habitat selection, individual and interspecific interactions, and population dynamics in Florida Bay to better inform future management decisions.

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