Spawning-related Movement Patterns of Goliath Grouper (*Epinephelus itajara)* Off the Atlantic Coast of Florida

Patrones de Movimiento Relacionados al Desove del Mero Guasa (*Epinephelus itajara*) en las Afueras de la Costa Atlántica de Florida

Modèles de Mouvement Liés à la Reproduction des Mérous Géant (*Epinephelus itajara*) de la Côte Atlantique de la Floride

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ABSTRACT

Goliath Grouper (*Epinephelus itajara*), the largest reef fish in the western Atlantic, was once relatively common throughout Florida and the Caribbean. Due to overfishing and loss of juvenile habitat, it is considered critically endangered (Craig 2011). However, under total protection since 1990, population recovery is occurring is the southeastern US. Spawning aggregations are now forming on the shelf off southeast and southwest Florida. Aggregations of 20 to over 100 individuals occur on specific sites, both artificial and natural sites, from late July through October. In an effort to determine the nature of spawning migrations, we implanted 40 adult Goliath Grouper with ultrasonic transmitter tags (VEMCO 69 kHz V16-P coded transmitters) on known spawning sites in 2010 and 2012. Tagged fish were tracked as they moved through the Florida Atlantic Coast Telemetry array of VEMCO VR2 and VR2W ultrasonic receivers. Results indicate that adult Goliath Grouper are relatively sedentary during non-spawning months (mean monthly distance moved = 1.98 km ± 0.6) but moved significantly more prior to aggregation formation in July (18.5 km ± 8.56). Tagged fish moved more during spawning months compared to non-spawning months. Multiple individuals were tracked moving long distances (> 300 km) between residence reefs and spawning sites. Site fidelity to aggregations was high: 84.2% of tagged fish returned to the site of tagging after one year and 77.8% returned after two years. Our study utilizes long-term tagging data of individual fish to aid in understanding the movement patterns of a large reef fish species of special conservation concern.

KEY WORDS: Grouper, spawning, movement, aggregation, Goliath Grouper

INTRODUCTION

The Atlantic Goliath Grouper (*Epinephelus itajara*) is the largest reef fish in the western Atlantic but has been over-fished to the extent that the IUCN has classified it as 'critically endangered' (Craig 2011). In the southeastern U.S., the population of Goliath Grouper has been steadily recovering following a recreational and commercial fishing moratorium enacted in 1990 by both the South Atlantic and the Gulf of Mexico Fishery Management Councils (Koenig et al. 2011). Currently spawning aggregations (SPAGs) of Goliath Grouper form annually during the late summer and early fall off both the Gulf and Atlantic coasts of Florida. Although Goliath Grouper form SPAGs, they are also known to exhibit a restricted home range and show high site fidelity to residence or home reefs (Koenig et al. 2007, Koenig et al. 2011). However, details about individual movement patterns of Goliath Grouper between home sites and spawning sites and specific behaviors during aggregation periods are unknown. Diver reports of Goliath Grouper sightings are increasingly common in areas not associated with spawning activity (Koenig et al. 2011). It is well known that SPAGs are composed of individuals derived from broad geographical areas; however, it is important to know how large that geographical area is and the consistency with which the fish move to spawning sites and back to home sites. Therefore, information on migration dynamics (distances, patterns, pathways and spawning site fidelity) is important for effective management.

We realized that we had a rare opportunity to monitor patterns of behavior related to Goliath Grouper reproduction in great detail by joining the Florida Atlantic Coast Telemetry (FACT) Array cooperative research group initiated and coordinated by Florida Fish and Wildlife Conservation Commission (FWC). The FACT group makes use of compatible telemetry technology and a commitment to coordinate receiver spacing and to share detection data which allows member researchers to track study animals over long durations and great distances. As of early 2013, the 16 member organizations of FACT maintained 201 Vemco VR2 and VR2W receivers over a 500-km span of Florida's Atlantic coast deployed along a continuum of coastal habitats from freshwater estuaries (e.g. Indian River Lagoon) to marine waters of the adjacent continental shelf. This cooperative effort allows us to monitor movements of Goliath Grouper over a very large area of the east coast of Florida, from Palm Beach County to the Florida-Georgia border. In 2010 we added ten Vemco VR2W receivers to the FACT array on suspect Goliath Grouper spawning sites offshore of Jupiter, FL. By capturing and tagging Goliath Groupers while they were at the SPAGs we were able to track them as they moved through the FACT array of acoustic receivers back to home sites and then again when they returned to SPAGs in following years. This study gives us critical insight into the behaviors of Goliath Grouper during spawning while they are aggregating, but also during the rest of the year when they return to their home reefs. It also allows us to estimate site fidelity to home sites and spawning sites.

Here, we present some preliminary results of the first two years of the study, 2011 and 2012, showing how Goliath Groupers move along the Florida Atlantic coast in relation to SPAGs.

METHODS

Beginning in September 2010, we tagged Goliath Groupers intraperitoneally with acoustic transmitter tags (Vemco V16-4H, Vemco Ltd.). The cylindrical tags (16-mm (diameter) x 68-mm) came equipped with an 8-year battery. Fish were captured at known and suspected SPAG sites offshore of Jupiter, FL, during the annual late-summer/early-fall SPAG. The Vemco acoustic tags "ping" a unique identifier code once every 5-minutes which is recorded by Vemco VR2W-69 kHz receivers anchored to the bottom. During the study we deployed ten VR2W receivers at 14 different known or suspected SPAG sites offshore of Jupiter, FL (see Figure 1). Additional acoustic receivers maintained by the Florida Atlantic Coast Telemetry (FACT) Array group greatly expanded our sampling area.

Detection data were downloaded into the Vemco VUE program (Vemco Ltd., Halifax, NS, Canada) and exported into Excel (Microsoft, 2007, Redmond, Washington). All detections were first scanned for false detections using a 2-detection within 20-minute filter criteria. False detections were eliminated and the remaining detection data were entered into an Excel database. Using these data we calculated a number of different metrics to determine annual site fidelity and individual movement patterns of tagged Goliath Groupers, including the number of individuals returning to tagging site annually, the number of individuals detected in the SPAG area, maximum distance moved per month or year (defined as the maximum distance moved by a transmitter-tagged fish between any two stations during a given time period), and the number of SPAG sites visited per spawning season. We tested for differences in these metrics attributable to sex (ANOVA) and size (ANCOVA) using the R statistical software (R Core Development Team, 2013, Vienna, Austria).

RESULTS

We tagged 40 Goliath Groupers with coded transmitter tags from 4 September 2010 to 25 May 2011. The majority of tagging effort took place in the fall of 2010 (38 of 40 fish tagged), with the remaining two transmitters implanted in May 2011. Tagging was conducted at three suspect SPAG sites off Jupiter, FL (Figure 1), two of which have since been confirmed as spawning sites: Zion Train (artificial reef, 28-meters depth; 25 fish tagged) and Three-Holes (natural reef complex, 17-meters depth; 5 fish tagged). Ten fish were tagged at the Gulfland wreck (artificial reef, 10-meters depth), which has been confirmed

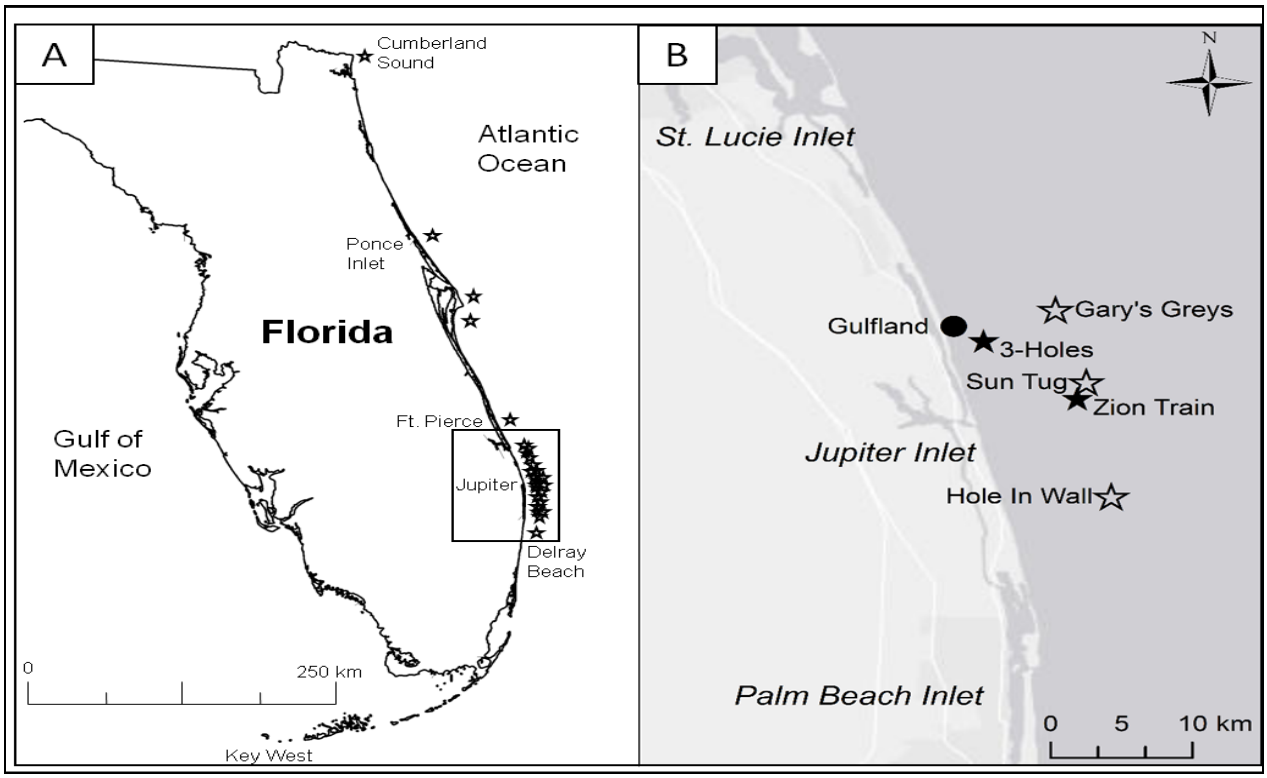

Figure 1. A: Locations of FACT monitored sites where acoustically tagged Atlantic Goliath Grouper were detected in 2011 and 2012; B: Locations of Goliath Grouper SPAGs (stars) and sites where Goliath Grouper were captured and tagged with acoustic transmitters (closed circle & closed stars).

as a non-spawning site. Tagged Goliath Groupers ranged in size from 104 to 205 cm total length (TL; mean TL = 159.1 cm). Sex distribution of tagged fish (as determined histologically from gonad biopsies or visually for males emitting sperm) was as follows: female = 17; male = 13; transitional = 6; immature = 3; unknown = 1 (the single "unknown" individual was excluded from analyses which compare movement patterns of males and females).

Between 1 January 2011 and 31 December 2012, transmitter-tagged Goliath Groupers were detected at 43 unique stations monitored by FACT (see Figure 1). During 2011, 37 of the 40 tagged Goliath Groupers (92.5%) were recorded at one or more sites within the array. In 2012, 35 of the 40 tagged Goliath Groupers (87.5%) were recorded at one or more sites within the array. Two individuals were never detected in the array subsequent to tagging. However, one of these individuals was recaptured during sampling approximately 4 months after being tagged; an acoustic receiver deployed at the site of recapture did not detect the fish, thus indicating a malfunctioning transmitter. The majority of detections occurred within 10-km of the tagging site, but tagged goliaths were detected at sites that spanned the entire range of the FACT array, a total distance of approximately 500 km.

Site fidelity of transmitter-tagged fish was high: 75% of fish tagged in 2010 and 2011 (30 of 40 fish) returned to the site where they were tagged within one year, and 25 of 38 (65.8%) returned to their tagging site in both 2011 and 2012 (we had only one full year of data for the two fish tagged in 2011 so these are not included here). All tagged fish, with the exception of the two that were lost since tagging, were detected at one of the five confirmed SPAG sites during the study (95%, 38 of 40 fish). Each year the number of tagged fish detected at spawning sites was the same - 85% or 34 of the 40 tagged fish visited a SPAG each year. Tagged fish visited an average of 1.78 ± 0.141 (mean ± SEM) SPAG sites over the course of the study. Tagged fish were detected at slightly more spawning sites in 2012 relative to 2011 (1.88 [± 0.212] vs. 1.70 [± 0.187]). A single tagged individual visited four SPAG sites in 2011; in 2012 a single individual was detected at all five confirmed spawning sites. All five confirmed spawning sites were visited by one or more transmitter-tagged fish during both 2011 and 2012.

The most frequently visited spawning site was "Zion Train" (ZT) which was the site where most fish were tagged. In 2011, 28 of 40 (70%) tagged Goliath Groupers were detected at ZT; in 2012, 21 of 40 (52.5%) of tagged Goliath Grouper were detected at ZT. Over both years, 29 of the 40 (72.5%) tagged Goliath Groupers were detected at the ZT site, followed by "Sun Tug" (26 tagged fish), "MG-111" (17 tagged fish), "3-Holes" (12 tagged fish), and "Gary's Greys" (12 tagged fish).

The number of FACT-monitored stations visited by transmitter-tagged Goliath Grouper during the study varied seasonally. In both years of the study the number of stations visited peaked during July – September, indicating increased activity during the spawning season. Most individuals moved little outside of the late-summer spawning season, remaining at one or few nearby reefs. The number of sites visited each month for tagged Goliath Groupers ranged from 0.2 (± 0.07) sites in January 2011 to 2.65 (± 0.44) sites in September 2012. Over the two-years reported here, the average transmitter-tagged fish was detected at just over 5 monitored stations (5.03 [± 0.441]), with slightly more detections during 2012 compared to 2011 (5.53 [± 0.661] vs. 4.53 [± 0.582]). The maximum number of monitored stations visited by any tagged fish over the course of the study was 20.

Consistent with the patterns described above, tagged fish moved more often and farther during months associated with spawning activity than the rest of the year (Figure

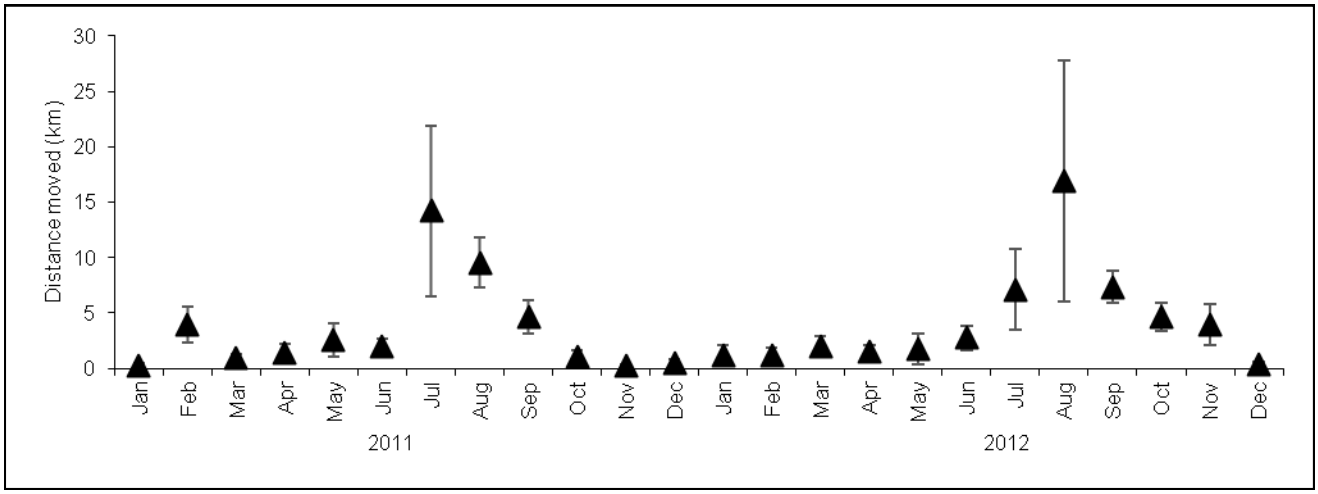

Figure 2. Distance moved along the east coast of Florida during each month of 2011 and 2012 by transmitter-tagged Atlantic Goliath Grouper. Error bars [± SEM].

2). Movement was generally above average from July – September each year with slight differences between the two years of the study: in 2011 peak movement occurred in July and was above the annual monthly mean (3.8-km per month) for August and September, while in 2012 tagged fish moved furthest in August and showed above average movement from July through November. Movement of tagged fish was also above average in February 2011.

The maximum distance moved between consecutive detections by a tagged fish in the study occurred between 11 and 21 August 2012 between Cumberland Sound near the Florida – Georgia state border and the SPAG site "MG-111" a total straight-line distance of 437.8-km. This same individual accounted for the second longest movement of 252.3-km over 22 days in July 2011 between a site located offshore of Ponce Inlet and "Tunnels", a natural reef site near the Jupiter, FL SPAG area. A different individual moved 222.1 km between Ponce Inlet and an artificial reef near Port St. Lucie, FL in 9 days, also during July 2011.

We analyzed the movement data to determine if any differences could be attributed to either fish size or sex. In general, larger fish visited more FACT-monitored stations during the study (Figure 3) and moved farther compared to smaller individuals. Linear regressions performed on the movement data showed a significant positive relationship between fish size (measured as total length) and the number of sites visited in 2011 (R^2 = 0.294; $F(1, 38)$ = 17.2; p = 0.00018) and 2012 (R^2 = 0.248; $F(1, 38)$ = 13.9; p = 0.00063). ANCOVA results showed these regressions were not different from each other ($F(2, 77)$ = 16.8; p = 0.19), suggesting these trends were consistent between the two years of the study. We found no differences between sexes in terms of the number of stations visited. However, the maximum distance moved by females was significantly greater than the distance moved by either males or transitional fish ($F(2, 69)$ = 3.22; p = 0.046).

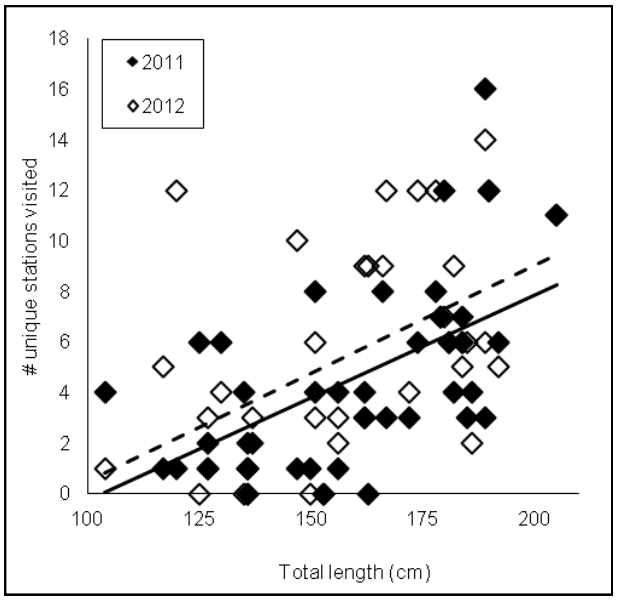

Figure 3. Number of unique FACT-monitored stations visited annually by transmitter-tagged Atlantic Goliath Groupers during 2011 (closed marks) and 2012 (open marks). Linear regressions were performed separately for each year (2011 = solid line; 2012 = dashed line), but were not significantly different from each other (ANCOVA: [$F(2, 77)$ = 16.8; p = 0.186]).

Analysis of transmitter-tagged fish movements suggests a strong lunar component to spawning site fidelity (Figure 4). In both years the number of transmitter-tagged goliaths recorded at the ZT site peaked during the new moons of August and September.

DISCUSSION

Monitoring of transmitter-tagged Goliath Grouper revealed that they do not, on average, move very far or very often, except around spawning time. This point was suggested by Koenig et al. (2011) from mark-recapture data and is confirmed by this study. By transmitter-tagging fish caught during the SPAG in 2010 we were able to passively track fish as they moved back to home sites and then returned to the SPAG area in 2011 and 2012. Some fish never left the SPAG area: on average 4 to 6 tagged individuals were detected daily at the ZT spawning site year-round. Likewise, detection data from the "3-Holes", "MG-111", and "Sun Tug" spawning sites all recorded the presence of resident individuals that remained at these sites all year. Another group of Goliath Groupers (7 individuals) was detected in the vicinity of a group of artificial reefs offshore of St. Lucie Inlet, approximately 25 km north of the spawning area. Individuals from this group made multiple movements between their home sites and the SPAG sites during the spawning season (July – September). After spawning, these fish returned to the St. Lucie reefs and did not return to Jupiter until the spawning season of the following year.

We concentrated most of our tagging effort on the ZT site because in both 2010 and 2011 this was the site of the largest aggregation in the offshore Jupiter area and was a presumed spawning site when the study started in 2010. Our estimates of site fidelity suggest that most fish return to the same sites year after year. However, in this area there are multiple aggregations in relatively close proximity and fish not only visited the aggregation where they had been tagged, but multiple others as well. Six of the 15 fish that were tagged at other sites visited the ZT site at some point during the study.

The tagging data suggest that Goliath Groupers move from residence or home sites to SPAG sites starting in July and remain relatively active throughout the spawning period. Our data suggest a strong connection between reproductive behavior of Goliath Grouper and the lunar cycle. We observed increased movement of tagged fish coincident with the July full moon. During this time fish

were actively moving between sites and into the spawning area offshore of Jupiter, FL. This was followed by aggregations that peaked in density during the August and September new moon (see Figure 4). It appears that the July full moon triggers Goliath Grouper to begin moving into the aggregation area, while spawning is triggered by the new moon. Complementary data on the occurrence of early POFs indicates that peak spawning occurs on new moons of August and September (Koenig and Coleman 2013).

We also observed what may be environmentally forced movements, such as those potentially induced by cold-water upwelling events that are known to occur in the study area. In February 2011 the monthly movement data was greater than average at a time when such movements would not be expected. It is possible that the elevated movements recorded in February 2011 represent tagged fish moving in response to variable environmental conditions. Unfortunately, we do not have corresponding temperature records to confirm this hypothesis. Since late 2012 we have attached temperature loggers to our receivers to evaluate the influence of cold temperatures on movements. It is well known that Goliath Grouper are sensitive to cold temperatures—temperatures below 15^{o}C can be lethal (Sadovy and Eklund 1999).

Detection range was not explicitly tested for this study. However, other studies using these same acoustic tags report detection ranges between 50 and 750 m, with peak efficiency occurring between 250 and 500 m (Humston et al. 2005, Whitty et al. 2009). Based on diver observations, Goliath Groupers tend to stay close to structure, well within the detectable range of the transmitters. Furthermore, even the maximum detection range of 750-m is much less than the distance between sites, allowing us to assume that single individuals cannot be detected at multiple sites simultaneously. The detection filter we used to eliminate false detections (i.e., 2 detections within 20 minutes) was designed to eliminate false detections that can occur when multiple transmitter codes arrive at the receiver at the same time, sometimes causing the receiver to record anomalous tag identifiers. Our detection filter follows the recommendations of the transmitter manufacturer to reduce the likelihood of such "collisions" from being recorded in the data.

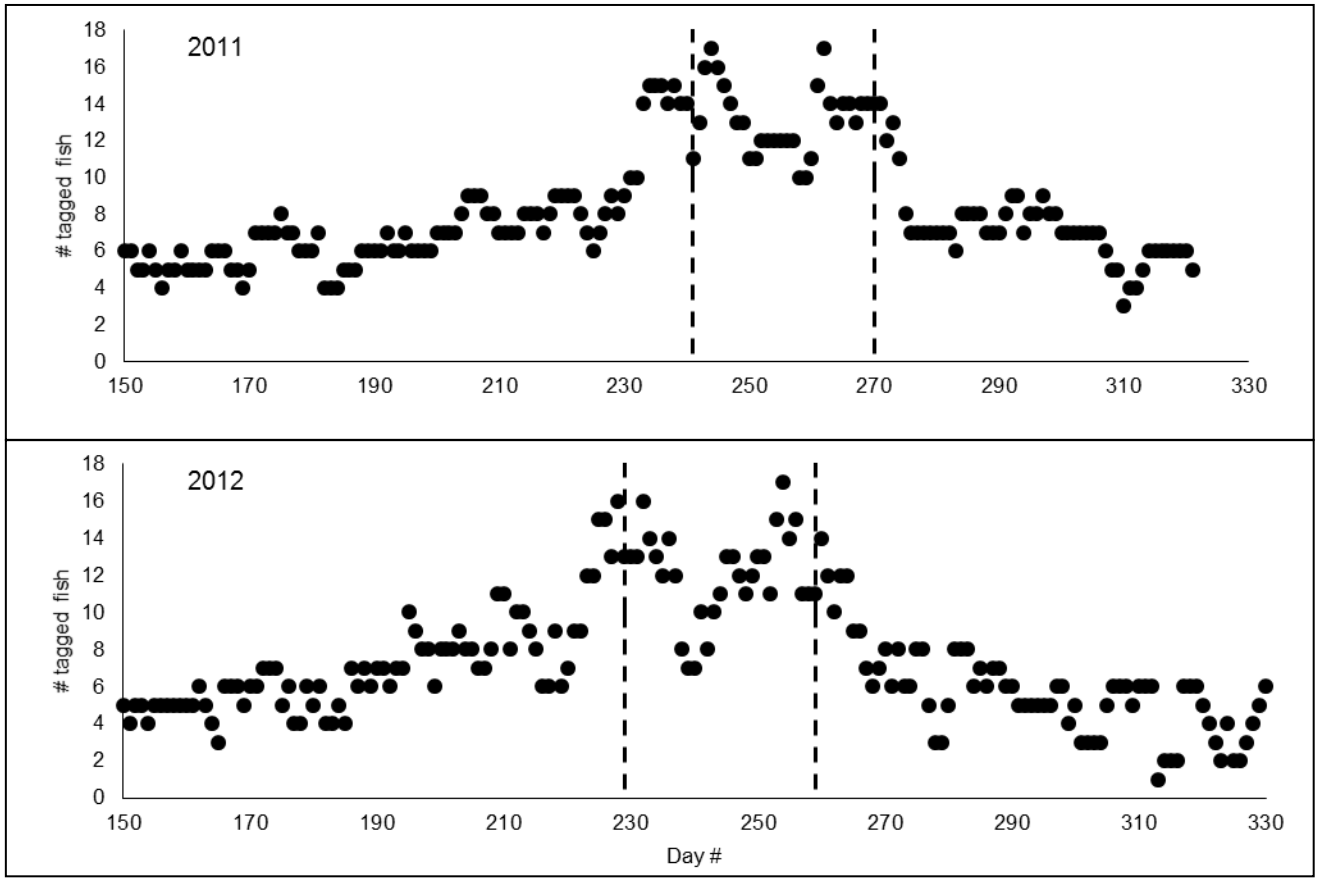

Figure 4. Number of acoustically-tagged Goliath Groupers detected at the Zion Train SPAG site located offshore of Jupiter, FL, during the spawning seasons of 2011 (top) and 2012 (bottom). The dashed vertical lines indicate the approximate dates of the new moons in August and September of each year.

This study highlights the importance of continuously monitored reef sites, such as the FACT Array, for the study of movements of reef-associated species. Little detail on movements can be gained without such a cooperative system, but the FACT system, among other things, allowed us to confirm a single spawning area off Palm Beach and Martin Counties and extensive migrations from the full extent of the FACT array. Thus a main conclusion from this work is that the SPAG sites located off the east coast of Florida are composed of Goliath Groupers derived from the entire east coast of Florida and probably also include fish from Georgia. That these individuals were found to return to the same spawning sites over consecutive years is an important insight into the aggregating behavior of this critically endangered species.

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