An evaluation of the effects of catch and release angling on survival and behavior of Goliath grouper (*Epinephelus itajara*) with additional investigation into residence and long-term movement patterns

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TABLE OF CONTENTS

Executive Summary 4

Research Purpose and Goals 5

- Identification of the problem 5
- Project objectives 6
- Justification for government assistance 7

Research Approach and Methods 7

- Study area and site designation 7
- Acoustic receiver deployment and array design 8
- Acoustic tagging of Goliath grouper 8
- Visual surveys of study sites 9
- Data analyses and statistics 9
- Project management 10

Research Results and General Findings 10

- Catch and release mortality and barotrauma 11
- Monitoring periods and residence time 11
- Forays and seasonal movements 11
- Rates of movement 12
- Fine scale diel and seasonal patterns in vertical activity 12
- Recaptures of tagged individuals 13
- Visual surveys of study sites 13

Evaluation and Discussion 14

- Catch and release mortality and barotrauma 14
- Residence time and site fidelity 15
- Distances moved and rates of movement 17
- Diel and seasonal patterns in vertical movements 17

Conclusions and need for additional work.....18

Dissemination of project results.....19

Acknowledgements.....20

Literature Cited.....21

Tables and Figures.....29

Table 1. Site characteristics of acoustically monitored artificial reefs.....30

Table 2. Individual details of acoustically monitored Goliath grouper.....31

Table 3. Seasonal departures of Goliath grouper during spawning periods.....34

Figure 1. Map of study area and monitored sites.....35

Figure 2. Goliath grouper abundance data from visual surveys at primary sites.....36

Figure 3. Image of externally attached acoustic transmitter.....37

Figure 4. Daily presence of acoustically tagged Goliath grouper at monitored sites.....38

Figure 5. Barotrauma severity by depth of capture.....39

Figure 6. Barotrauma severity as related to monitoring period and total length.....40

Figure 7. Hourly depth position of Goliath grouper for 24 hours post-release.....41

Figure 8. Total length and residence of Goliath grouper as related to capture site.....43

Figure 9. Total monitoring periods and residence indices by total length.....44

Figure 10. Size specific departure of Goliath grouper during spawning season.....45

Figure 11. Rates of movement for Goliath grouper moving between sites.....47

Figure 12. Position within the water column as a function of month and hour.....48

Figure 13. Position within the water column as a function of site volume, relief.....49

Figure 14. Monthly number of detections within each quarter of the water column.....50

Figure 15. Examples of potential catch and release mortality or recapture.....51

Figure 16. Size distribution and abundance observed during visual surveys.....52

Executive Summary

The Goliath grouper (*Epinephelus itajara* Lichtenstein 1822) is one of the world's largest groupers, and has experienced significant overfishing throughout its geographic range. The species has been protected from harvest within the United States since 1990, but fisheries persist in other regions of the Western Atlantic and Caribbean Sea. The Goliath grouper is listed internationally as critically endangered according to the International Union for the Conservation of Nature (IUCN), and the overall status and recovery of the species throughout its entire geographic range remains uncertain. Within the U.S., the population has responded encouragingly to protection and has shown signs of increasing abundance in recent years. An active catch and release fishery has developed in Florida, and increasing interactions with anglers and divers have created a push by some recreational and commercial fishing sectors to lift the moratorium. Prior to allowing any level of harvest, a stock assessment is warranted; however, because harvest is prohibited and traditional fishery-dependent data are unavailable, recent attempts to assess the status of the stock have failed due to a lack of information.

Protection from harvest does not immediately imply that fishing mortality is negligible. Total mortality estimates are therefore uncertain and additional data are needed regarding Goliath grouper survival after capture. Catch and release may induce barotrauma and require extensive boat-side handling that can result in injury or mortality. Additionally, because Goliath grouper are suspected to exhibit strong site fidelity, repeated capture events over time may lead to decreased survival of fish at sites visited regularly by anglers. The first goal of this study was therefore to identify the immediate effects of catch and release angling upon the behavior and survival of Goliath grouper. The second goal of this study was to characterize the long-term site fidelity and residence times of Goliath grouper and identify fine-scale patterns in individual movement. This information was previously unavailable and is relevant for future stock assessment and management of this valuable marine species.

Goliath grouper (105 – 206 cm TL) were acoustically tagged during catch and release events at artificial reefs (8 – 40 m deep) within the central eastern Gulf of Mexico. An array of acoustic receivers was deployed throughout the study area and allowed for continuous monitoring of tagged individuals for up to 950 days after release. Barotrauma severity increased with capture depth, but immediate or delayed mortality was not observed. Within 24 hours after catch and release, all individuals had resumed vertical movement within the water column. Most individuals were relatively sedentary and faithful to a specific site for months – years, but long distance movements (> 150 km) were observed and demonstrated the capacity of some individuals to move over broader geographic scales. During all three years of this study, there was a concerted departure of mature sized fish (>140 cm) during the reproductive period. The destination of these individuals remains unknown, but the departure and subsequent return of fish coincident with the spawning season is suggestive of a spawning migration. Future efforts to identify spawning sites within the eastern Gulf of Mexico are warranted.

Total monitoring period was not related to the severity of barotrauma or the length of handling time, which suggests that with proper handling Goliath grouper are not subject to high levels of release mortality within the study area. However, the strong site fidelity of Goliath grouper to artificial reefs increases susceptibility to fishing pressure and amplifies interactions with anglers, so the chronic effects of repeated capture upon growth and survival of individuals over many years remain unclear.

Research Purpose and Goals

Identification of the problem

The Goliath grouper (Epinephelidae: *Epinephelus itajara* Lichtenstein 1822) is the world's second largest grouper, and occurs within tropical and subtropical waters of the Atlantic Ocean and Gulf of Mexico (Craig et al., 2011). Individuals may achieve sizes exceeding 400 kg and 200 cm in total length (TL), and can live at least 37 years (Bullock et al., 1992). Like many large, long-lived marine species, the Goliath grouper has experienced overfishing and suffered significant population declines (Sadovy and Eklund, 1999; Musick et al., 2000). At least one quarter of all Goliath grouper spawning aggregations were believed to be extirpated in 2000 (Musick, 2000). The species has been protected from all harvest within the United States since 1990 (GMFMC, 1990; SAFMC, 1990), and in 1994 was listed internationally as critically endangered on the International Union for the Conservation of Nature (IUCN) Red List (www.iucnredlist.org) (Pusack and Graham 2009). The species has since been protected in Brazil (2002), Puerto Rico (2004) and the US Virgin Islands (2004; NMFS, 2006). However, fisheries persist for Goliath grouper in other parts of the Caribbean and South Atlantic, and the overall health and recovery of the species throughout its entire geographic range remains unclear.

The Goliath grouper is slow-growing, late to mature, and aggregates to spawn, which are all factors that significantly increase vulnerability to overfishing (Bullock et al., 1992; Eklund and Schull, 2001). Because these life history characteristics make the species especially susceptible to exploitation, any changes in regulation should proceed cautiously (Musick et al., 2000; Rhodes and Graham, 2009). Within the U.S., the population has responded encouragingly to protection and has shown signs of recovery in recent years (Cass-Calay and Schmidt, 2009; Koenig et al., 2011), and NOAA removed Goliath grouper from the Species of Concern list in 2006 (NMFS, 2006). However, the fishing moratorium remains in place at this time due to uncertainty regarding overall population status and level of recovery.

The impressive size and charismatic reef presence of Goliath grouper make them a favorite of the underwater tourism industry (Lorenzen et al., 2013), and their economic impact has been argued to be greater as a protected species than a harvested one (Frias-Torres, 2012). However, a growing public perception that the species is rebounding has created a push among some recreational and commercial fishing sectors for a harvest fishery to be reopened (Lorenzen et al., 2013; FWC, unpublished data). As the population rebuilds and interaction with anglers increases, pressure to lift the fishing moratorium is likely to escalate. Prior to allowing any level of take, a stock assessment is warranted; however, because harvest is prohibited, traditional fishery-dependent data are unavailable, and recent attempts to assess the status of the stock have failed due to a lack of information (SEDAR 6, 2004; SEDAR 23, 2011). For example, total mortality estimates remain uncertain since protection from harvest does not immediately imply that fishing mortality is negligible (Casey, 1996; Porch et al., 2006).

Recreational fishing charters that operate throughout the central eastern Gulf of Mexico advertise Goliath grouper as a prime target species for catch and release fishing. The species is also regularly caught unintentionally during recreational and commercial fishing efforts for other reef species (SEDAR 23, 2011). The Goliath grouper is a relatively nearshore and shallow-water species (typically < 50 m) that aggregates at high relief habitats, particularly artificial reefs (Sadovy and Eklund, 1999; Koenig et al., 2011; Collins, 2014). The locations of these sites are

often publicly available and relatively easy for anglers and divers to locate, increasing the potential for interaction between resident fish and humans (Huntsman et al., 1999). Indications of high site fidelity (Eklund and Schull, 2001; Koenig et al., 2011) suggest that Goliath grouper remain resident at predictable locations and therefore would be subject to repeated catch and release at sites with high fishing activity. The impact upon the behavior and survival of Goliath grouper after these interactions with anglers has not been previously described.

Project objectives

The main objective of this work was to provide additional information regarding Goliath grouper that would be relevant for management and assist with future stock assessment. Research priorities for this species were identified during the SEDAR 6 workshop in 2004, and this project directly addressed several of the top priorities, including collection of information regarding demographics and mortality sources (see SEDAR6 2004, p. 8-9):

"The issue of ongoing mortality was of critical concern to the Review Panel. Anecdotal information with regard to various sources of this mortality was presented. These sources included longline by-catch, post-release mortality, and illegal harvest. It is extremely important that these sources of ongoing mortality be identified and the magnitude of this mortality estimated."

The first goal of this study was therefore to identify the immediate effects of catch and release angling on the behavior and survival of Goliath grouper. Immediate mortality after catch and release is difficult to quantify through conventional tagging, which depends upon recapture reports that may take months to years (Sumpton et al., 2010). Monitoring survival in holding bins or cages post-release (e.g., Jarvis and Lowe, 2008; Brown et al., 2010), or through experimental procedures in the laboratory (e.g., Rogers et al., 2008; Campbell et al, 2010) are not practical for adult Goliath grouper considering their large size. Acoustic telemetry was therefore employed to monitor fish survival and behavior directly after catch and release, which allowed for a realistic mimic of fishing activity and provided fine scale information that conventional tags or other experimental techniques could not (e.g., Afonso et al., 2012; Bryars et al., 2012).

The second goal of this study was to characterize the survival, site fidelity and residence time of tagged Goliath grouper over extended time frames (1 – 2 years), and to identify seasonal and diel patterns in movement of individuals within the study area. Continuous tracking of individuals over extended periods can provide fine scale information regarding the long-term survival and behavior of protected species that may otherwise be unavailable (Wearmouth and Sims 2009; Simpfendorfer et al., 2011; Bryars et al., 2012). For instance, monitoring seasonal patterns in movement allow for a description of an animal's home range over varying temporal scales that can assist in the identification of essential fish habitats and inform fishing regulations (Botsford et al., 2003; Topping et al., 2006; DeCelles and Cadrin 2010; Kneebone et al., 2012). Additionally, residence time and site fidelity as they relate to particular variables (habitat type, habitat size, and presence of conspecifics) can provide information regarding the ecological importance of specific areas to a given species (Matthews, 1990; Heupel et al., 2007; Meyer et al., 2007; Botsford et al., 2009; Lowe et al., 2009). The ease of catchability combined with the life history characteristics of Goliath grouper make the quantification of release mortality, site

fidelity, movement patterns and habitat preferences especially important concerns in the development of future management strategies for this vulnerable marine species.

Justification for government assistance

Pursuant to MARFIN research priorities, this project addressed topics relevant to rebuilding over-fished marine fisheries and integrated the conservation of a protected species with fisheries management. Specifically, this research best fit the following criteria defined within the 2010 FFO: p. 3 [1.Bycatch. (d) Characterize and assess the impact of bycatch of regulatory discards in recreational reef fisheries including depth-related release mortality for species caught with hook and line]; p. 4-5. [2. Reef Fish (a) Collection of basic biological data for species in commercially and recreationally important fisheries; (5) (a) Examine retention and residency of reef fish species. Examine temporal and spatial differences in the size at age, size at maturity and other life history characteristics; and (b) Genetic research on stock structure of recreationally important reef fishes in the Gulf].

Research Approach and Methods

Study area and site designation

The comeback of Goliath grouper is especially evident along the west coast of Florida, an historical center of abundance for this species, and one of the few areas that has been able to sustain an undeveloped stretch of critical mangrove nursery habitat (Koenig et al., 2007). Before the harvest moratorium was implemented in 1990, the majority of commercially harvested Goliath grouper were also landed within this region (Bullock et al., 1992), making the study area an ideal location for this research.

Fishing sites for catch and release of Goliath grouper were chosen based upon habitat type, depth and location within the central eastern Gulf of Mexico (Fig. 1). Prior work (Collins and Barbieri 2010) demonstrated Goliath grouper preference for artificial reefs within the study area, and six primary sites (P1 – P6) were selected from previously characterized artificial reefs for which Goliath grouper abundance data were already available (Fig. 2). An additional six accessory sites (A1 – A6) were opportunistically monitored as time and weather conditions allowed. Sites were chosen to represent a range of artificial reef sizes, varying in relief, footprint area (total length × total width) and volume (Table 1). In order to assess the effects of potential barotrauma with increasing capture depth, sites were distributed from 12 to 40 m (10 – 70 km from shore), which represents the general depth range for Goliath grouper (Bullock et al. 1992; Sadovy and Eklund 1999; Gerhardinger et al., 2006) and also the typical range of recreational fishing effort for this species in the eastern Gulf of Mexico (FWC, Fisheries-Dependent Monitoring Program, pers. comm.). Finally, sites were picked based upon relative proximity to each other in order to maximize the odds of detecting fish moving between sites (Fig. 1).

Acoustic receiver deployment and array design

Acoustic receivers (Vemco VR2Ws) were deployed throughout the study area to detect Goliath grouper that were acoustically tagged during catch and release events. Prior to tagging any fish, detection tests were performed at each of the six primary sites (P1 – P6) to ensure that receivers were placed properly for optimum detection of acoustic tags (> 90 % detection rate; McWhorter and Collins, 2011). In order to maximize detection of fish regardless of fish position around the artificial reef, multiple acoustic receivers (two to four VR2Ws, depending on site size) were positioned 50 – 100 m from the center of each primary site. This placement was considered to be conservative, as these receivers have a listening radius of approximately 150 – 750 m depending upon environmental conditions (Pincock 2008). Single receivers were also deployed in the same fashion at the six accessory sites (A1 – A6) to extend acoustic coverage within the study area. Detection tests were not performed at the accessory sites; however, the depth range and habitat characteristics of these sites were similar to primary sites and the detection capability was assumed to be similar (Table 1). Prior to deployment, receivers were coated with a copper based antifouling paint to prevent biofouling and the associated reduction in detection capability (Heupel et al., 2008). All receivers were maintained and downloaded at least quarterly.

Acoustic tagging of Goliath grouper

Goliath grouper were caught between April 2011 and December 2012 using either rod and reel or hand-lines fitted with 12-0 circle hooks and baited with dead fish, which are typical methods utilized by recreational anglers who target this species. Gear type, handling time (HT; time from bite until release), hook position, and fish total length (TL, cm) were recorded. Fish were inspected visually and the level of barotrauma (BT) was assigned a qualitative value of 1, 2 or 3, where (1): minimal with no external signs of trauma and descent occurred immediately and independently upon release without venting; (2): moderate with signs of gas bladder expansion (bloated body cavity) but no other signs of trauma, and venting was required for independent descent; and (3): severe, with external signs of trauma including an everted stomach, intestinal protrusion from the anus, or evidence of exophthalmia; multiple venting procedures required before the fish was capable of independent descent. Fish were vented by inserting a large stainless steel hollow needle (300 mm x 5 mm) through the tissue behind the pectoral fin until it punctured the gas bladder. Whether or not fish were required to be hauled on board the vessel to achieve an adequate vent (versus vented boat-side and in the water) was also recorded and given a ‘yes’ or ‘no’ value.

All captured fish were fitted with a pressure sensitive acoustic transmitter (Vemco V13P-1L 69kHz; estimated battery life = 684 d) and a conventional identification (ID) tag. A pressure sensor within the acoustic tag allowed for the transmission of depth data for tagged individuals every 60 – 180 seconds. Although there was some concern about tag retention of externally attached transmitters, it was necessary to mimic catch and release as closely as possible to recreational angling events. For this reason as well as the large size of the study animals, transmitters were attached externally to avoid the additional stress associated with surgery and internal implantation. Transmitters were anchored securely beneath the dorsal fin rays (Fig. 3). Conventional ID tags were attached on the same side of the animal anterior to the transmitter and displayed a unique ID number large enough to be read by divers underwater, as well as the FWC

tagging hotline phone number to facilitate diver and angler reports of tagged fish. Both tags were sprayed with clear antifouling paint (AquaGard Alumi-Koat, Flexdel Corporation, Lakewood, NJ, USA) to discourage invertebrate and algal growth. Fin clips to be used for genetic analyses were also taken from all individuals and submitted for processing to the FWRI genetics lab.

Visual surveys of study sites

To assess Goliath grouper abundance and size distribution at acoustically monitored sites, visual SCUBA surveys were performed approximately every other month (2011 – 2013) at each of the six primary sites (P1 – P6). The six accessory sites (A1 – A6) were also surveyed opportunistically throughout this period (Table 1). During each survey, the same researcher (ABC) swam methodically from one end of the site to the other, checking all holes, crevices and the surrounding perimeter for Goliath grouper. This process was then repeated in reverse so that the entire length of the site was surveyed at least twice. To avoid error associated with double counting individuals, abundance estimates were recorded as the maximum number of fish encountered during a one-way survey of the site. All fish within the field of view of the diver were recorded and filmed using a high definition digital video camera (Sony HDR Handycam CX550) within an underwater housing (Light and Motion Bluefin) fitted with a custom made laser measuring device that projected equidistant green laser points (20 cm apart) onto the fish. Still image frames in which fish were filmed perpendicular to the camera were removed from the video, assessed using image analysis software (Image Pro Plus, Media Cybernetics Inc., Rockville MD, USA) and analyzed to obtain total length estimates of Goliath grouper (+/- 1 cm total length, TL). Video analysis also allowed for identification of specific individuals and for confirmation of abundance estimates recorded in the field. Surveys performed in visibilities less than 5 m or lasting less than 15 minutes were not considered in the results.

Data analysis and statistics

Acoustic data were analyzed to determine short term survival after catch and release, to assess site fidelity and behavioral patterns of fish at each monitored site, and to describe movements among sites within the study area. Duplicate and spurious detections were removed from the data prior to analysis. Acute survival and subsequent behavior after catch and release were monitored by assessing fish movement within the water column, as indicated by pressure sensors within acoustic tags (which transmitted a depth position every 60 – 180 seconds). Total monitoring period (TMP) for each individual was calculated as the number of days between tagging and the last detection recorded. Residence indices (RI) were calculated for fish at their tagging site (RI_{TS} = total days detected at tagging site/TMP) as well as within the entire study array (RI_A = total days detected within array/TMP) to identify residence times and site fidelity for a specific site and within the study area, respectively. The relationship between TMP and RI to the site of tagging and level of barotrauma were compared using the Kruskal-Wallis One-Way ANOVA. TMP and RIs were compared to site depth and fish total length using the Pearson Correlation.

General rates of movement (ROM) were calculated for fish that moved between sites within short intervals (<24 hours). When fish were observed to move between sites within 24 hours, the

ROM was calculated by dividing the distance between sites by the travel time (the time between the last detection at one site and the first detection at another). ROMs were compared to fish TL using linear regression.

To identify seasonal, diel or site-specific patterns in fish movement within the water column, depth data from pressure sensors were standardized across all fish to indicate fish depth position as a proportion of the water column (POS). This calculation simply divided the individual fish depth by the maximum water depth at the site of detection (i.e., POS at the bottom would equal 1.0 and POS at the surface would equal 0.0). To identify patterns in fish vertical activity, the relationship between POS and month, time of day and site were compared using generalized linear mixed models (Proc Glimmix in SAS).

To identify whether the residence times were related to the number or size distribution of conspecifics, data from visual surveys were tested for a relationship between RI_{TS} and Goliath grouper abundance or size distribution at that site (Kruskal-Wallis one-way ANOVA). All statistical analyses were performed using either SigmaPlot 12.5 (Systat Software Inc., San Jose CA, USA) or SAS Enterprise (SAS Institute Inc., Cary NC USA).

Project management

All technical aspects of this project were managed by Angela B. Collins and Luiz R. Barbieri. Collins maintained communications with participating anglers, performed all of the necessary field work, analyzed data collected, and summarized research progress in required reports. Barbieri oversaw the project through completion, performed quality control of research progress, and assisted with the interpretation and summarization of final results.

The project's performance was monitored through semi-annual MARFIN reports, prepared by Collins and reviewed by Barbieri, in accordance to NOAA/NMFS deadlines. Financial and administrative requirements were monitored for FWRI by Linda Torres, the FWRI Operations and Management Consultant Manager.

Research Results and General Findings

Acoustic tags were deployed on 39 Goliath grouper in the central eastern Gulf of Mexico between April 11, 2011 and December 20, 2012 (Table 2; Fig. 4). The total number of detections per individual (after the removal of duplicate and spurious detections) ranged from 2,232 – 721,263 (mean = 156,615), with an average number of 569 detections per day for each fish (range 20 – 1,463 detections per day). Tagged individuals ranged in size from 105 – 206 cm TL.

Catch and release mortality and barotrauma

Immediate or delayed mortality was not observed for any of the Goliath grouper caught during this study. Barotrauma increased at capture depths greater than 30 m (Fig. 5; $p < 0.001$; Kruskal Wallis one-way ANOVA), but was not related to fish TL ($p=0.288$) or total monitoring period (TMP; $p= 0.536$; Kruskal Wallis 1-way ANOVA; Fig. 6). Handling time ranged 3 – 62 minutes (mean HT = 10 min), and immediately after release, the majority of individuals descended to the bottom and displayed limited movement for several hours (Fig. 7). Average depth of released individuals was significantly deeper for the first 24 hours of monitoring than for the following 2 days ($p< 0.001$; Proc Glimmix). One fish provided no data during the first 24 hours because it left the site immediately and went undetected for almost 4 months after release (tag 5766), but this individual returned to the initial tag site 118 days after tagging. All other fish (n = 38) resumed movement within the water column at their tagging site within 24 hours, providing evidence of survival after catch and release.

Monitoring periods and residence time

Total monitoring periods (TMP, the length of time between the first and last detections) ranged 18 – 950 days (mean = 444 d). The total number of days for which individuals were positively detected (> 5 detections within 24 hours) ranged 18 – 736 days (mean = 253 d). Goliath grouper displayed strong site fidelity, exhibiting daily presence at a single reef for periods as long as 736 days (mean = 242 d; Fig. 8b). Most detections for fish occurred at their initial site of tagging (mean $RI_{TS} = 0.61$, range 0.02 – 1.0; Fig. 8c), but individuals were observed to move around the study area and 22/39 (56%) were detected sporadically at other sites within the array. Total proportion of time unaccounted for ($1 – RI_A$) ranged from 0 – 0.98 (mean = 0.34; Fig. 8d). Site of capture did not affect TMP ($p=0.440$), RI_{TS} ($p=0.815$) or time unaccounted for ($1 – RI_A$; $p=0.534$) (Fig. 8b – 8d). There was no relationship between the site of capture and Goliath grouper TL ($p = 0.06$; Fig 8a), and Pearson correlations indicated that fish size (TL) was also not related to TMP ($p = 0.733$), RI_{TS} ($p = 0.713$), or RI_A ($p = 0.449$) (Fig. 9).

Forays and seasonal movements

Although relatively faithful to a single reef throughout much of the study, periods of absence exceeding 7 days, termed hereafter as ‘forays,’ occurred for 28/39 (72%) individuals. Forays as long as 487 days (mean = 41 d) and as far away as 174 km (mean = 23.9 km) were observed, after which fish either returned to their initial site or appeared at another monitored site within the study array (Fig. 4). Almost all individuals that departed on forays (23/28, 82%) eventually returned to their initial tagging site. The remaining five individuals were detected elsewhere in the study array but did not return to their original site during the study period. Forays occurred sporadically throughout the year and timing and length of forays varied among individuals, with the exception of a concerted departure of tagged fish that occurred during the spawning season (June – September; Bullock et al., 1992). Over the three summers for which Goliath grouper were tracked, over 65% of tagged individuals that were present departed their resident sites between June 1 and September 15, typically within one week of each other, regardless of their

location (Table 3; Fig. 4). This seasonal departure was significantly related to fish total length (Fig. 10; $p < 0.001$), and departures were observed only for individuals that were > 140 cm TL at tagging. Interestingly, three smaller fish (134, 148 and 150 cm TL at tagging) that did not depart during their first year of monitoring did exhibit a seasonal departure during the spawning season of the following year (Fig. 11); however, because sizes were only measured at initial tagging, the exact sizes of these fish at the seasonal departure are unavailable. The destinations of fish during this seasonal departure are unknown, with the exception of two individuals. Tag ID 91 (202 cm TL, BT =3) appeared 174 km south of the study array at a shipwreck being monitored by another researcher (C. Koenig, Florida State University, pers. comm.). This individual exhibited daily presence at this site for two weeks before returning to the study area. Tag ID 81 (149 cm TL; BT = 2) left its tag site (P4) and appeared to the northwest at another site within our study array (P5), where it remained for one month before tag transmissions ended entirely (Fig. 4).

Rates of movement

Eleven Goliath grouper (122 – 202 cm TL; mean = 164 cm TL) swam between acoustically monitored sites within a single day (< 24 hours). Data from these fish were examined to assess general rates of movement (ROM). Since the direct path and behavior of an individual while travelling between sites was unknown, ROMs were calculated based on the assumption that fish moved in a straight horizontal line and did not stop. Therefore the ROMs calculated herein are likely an underestimate of actual swimming speed. Estimated ROMs ranged 0.52 – 2.87 km/h (mean = 1.49 km/h). There was no difference in ROM between individuals (One way ANOVA; $p = 0.248$), nor was there any relationship between ROM and TL (Proc Glimmix $p = 0.896$) (Fig. 11). The theoretical formula for the most energy efficient swimming speed in fishes ($U_0=0.503L^{0.43}$; Wiehs, 1977) predicts that a fish of 164 cm would move at approximately 0.62 m/s (2.23 km/h). ROM estimations calculated during this study were 0.54 – 0.68 m/s (1.9 – 2.5 km/h), so were well within the range of energy efficient swimming speeds for fishes of this size (Weihs, 1977).

Fine scale diel and seasonal patterns in vertical activity

Individuals spent the majority of their time associated with the structure near the bottom, in the lower quarter of the water column (Fig. 12). Vertical movement and activity within the water column was higher during the day for all months of the year (Fig. 12a; $p< 0.0001$, Proc Glimmix POS vs. Diel). Goliath grouper exhibited the greatest breadth of vertical activity during the early morning and early evening hours (Fig. 12b; $p<0.001$ Proc Glimmix POS vs. hour). Seasonal patterns in water column position were apparent, and fish position at each site was significantly higher during the spring and summer months (April – September; $p< 0.001$, Proc Glimmix POS vs. month, season; Fig. 12a). The smallest range of vertical movement was observed during January and February, when bottom water temperatures were the lowest (14 – 20°C; mean = 18°C over the course of this study). There was also a significant difference between sites and POS ($p<0.001$, Proc Glimmix, POS vs. site), where POS exhibited a positive relationship with site volume (ANOVA, $p = 0.025$) and site vertical relief (ANOVA, $p = 0.028$) (Fig. 13). Although the majority of time was spent in the lowest quarter of the water column, individuals

did make extreme vertical movements and were recorded throughout the entire water column to some extent during all months of the year (Fig. 14). Analysis of depth data showed that the final detection for all individuals occurred in the bottom quarter of the water column, except for one fish that was last detected at 0.0 m and then disappeared entirely (Fig. 15a).

Recaptures of tagged individuals

Multiple individuals (7/39, 18%) were recaptured by the authors at three different sites (depths of 19, 25 and 40 m) 13 – 445 days after initial tagging. Two of these individuals had lost their acoustic tags but were recaptured at their original site of tagging (372 and 445 days post initial tagging). Recaptured fish often had new hooks in their mouths (5/7) and were trailing fishing leaders (2/7) or lead weights (1/7), providing further evidence of periodic interactions with anglers. Acoustic data (depth positions) were assessed and compared with known recapture times to identify whether catch and release events were detectable. For the five fish that still had acoustic tags attached during recapture, ascent to the surface during these recapture events was only visible for two individuals (e.g., Fig 15b).

Visual Surveys of study sites

Underwater visual surveys (n = 285) were performed at least every other month from April 2011 until November 2013 at each of the six primary sites (Fig. 16) and opportunistically at the six accessory sites (Table 1) in order to assess *in situ* Goliath grouper abundance and size distribution at monitored reefs. The maximum number of individuals observed during a visual survey was 26 (mean = 7). Lengths of Goliath grouper that were verified through video image analysis ranged from 61 to 215 cm TL (mean = 128 cm TL). Throughout the study, the majority of individuals observed were 100 – 150 cm TL (Fig. 16). There was no significant relationship between fish size and site depth (Proc Glimmix; $p = 0.8171$). Individuals as small as 61 cm TL were verified from sites as far as 50 km from shore and as deep as 30 m, and individuals as large as 200 cm were verified at sites within 10 km from shore as shallow as 12 m. As expected from related work (Collins, 2014), the highest numbers of Goliath grouper were observed at the largest artificial reefs. However, residence times of individual fish (RI_{TS}) were not related to site size or to the mean number of other Goliath grouper present throughout the study period. There was no relationship between the size distributions of Goliath grouper and site, depth or season, and sizes of observed fish were relatively consistent at each site throughout the year, even during reproductive periods (Fig. 16).

Evaluation and Discussion

The initial goals and objectives of this project were attained, without modification to the initial proposal, with the exception of a no-cost extension that was requested so that data collection could continue through the battery duration of several acoustic tags deployed late in 2012.

Catch and release mortality and barotrauma

Mortality due to catch and release has not previously been quantified for Goliath grouper, but it is an important consideration during stock assessments and overall management of marine species (e.g., Bartholomew and Bohnsack 2005; Arlinghaus et al., 2007; Campbell et al., 2010). Species with high site fidelity and predictable movement or migration patterns are more vulnerable to exploitation because they are easier to locate than those that exhibit irregular or random behavior (Polunin and Roberts 1996; Huntsman et al., 1999; Cheung et al., 2007). Although Goliath grouper are prohibited from harvest within the U.S., their high site fidelity and tendency to aggregate at artificial reefs in nearshore waters make them susceptible to relatively high levels of capture, either through directed catch and release efforts or through incidental fishing pressure by anglers targeting other species (SEDAR 23, 2011).

Barotrauma severity increased with capture depth but was not related to Goliath grouper size, and immediate mortality following catch and release was not observed during this study. Pressure related fishing trauma typically increases with capture depth (Feathers and Knable, 1983; Gitschlag and Renauld, 1994; Arlinghaus et al., 2007; Jarvis and Lowe, 2008; Campbell et al., 2010), and the most extreme cases of barotrauma for Goliath grouper occurred at sites deeper than 30 m. These fish exhibited gas bladder expansion, stomach eversion and intestinal protrusion from the anus; however, exophthalmia was not observed. Extreme cases of barotrauma observed during this research required lengthy and multiple venting procedures before fish were able to descend independently. It should be noted here that all of the fish suffering from moderate or extreme barotrauma were vented until they could descend independently, a procedure that has been identified to significantly reduce mortality in other species (e.g., Feathers and Knable 1983; Wilson and Burns, 1996; Collins et al., 1999; Alos, 2008; Butcher et al., 2012). Goliath grouper suffering moderate to extreme barotrauma often were required to be hauled on board in order to release enough gas for the fish to descend independently, and handling times associated with tagging lasted up to 62 minutes (from capture to release), which may not always be practical or possible for recreational catch and release anglers.

Pressure sensitive acoustic tags provided a depth data point every 90 – 180 seconds, and allowed for a detailed description of behavior immediately after catch and release. Although most fish descended directly to the bottom and remained relatively immobile for the first few hours following release, all resumed movement in the water column within 24 hours and provided data for at least two weeks and up to almost three years after release. These data suggest minimal immediate or delayed mortality and indicate that Goliath grouper are able to handle catch and release relatively well if they are vented, at least for the depths fished during this research (to 40 m). Since this species is rarely observed at depths > 50 m (Sadovy and Eklund 1999; Gerhardinger et al., 2006; Craig et al., 2011) and most recreational fishing on the west Florida

shelf occurs inside of this depth range (FWC Fisheries-Dependent Monitoring Program, pers. comm.), interactions between anglers and Goliath grouper at depths greater than 40 m are expected to be minimal in this region. Evidence of residual fishing gear in recaptured Goliath grouper included new hooks and trailing fishing leaders, confirming that periodic interactions between this species and anglers within the study area are common. Fish that everted their stomachs during barotrauma exhibited fishing gear lodged within the stomach (monofilament fishing line, hooks, fishing lures, lead weights). Ingested fishing tackle is likely due to Goliath grouper predation upon other fish being reeled in by anglers rather than targeted catch and release activities. Although the repeat interval on the acoustic tags was not rapid enough to detect all recapture events, the telemetry data did reveal one fish that ascended from the bottom to the surface within 3 minutes, and then disappeared entirely from the study array (Fig. 14). This could potentially be indicative of catch and release mortality, illegal harvest, tag malfunction or tag removal by the angler. Further investigation into this area is required, but even so, the extended monitoring periods observed for most individuals suggest that illegal harvest is not an overwhelming issue within the study area. Acute mortality due to catch and release appears to be minimal, but the chronic effects of repeated capture and ingestion or entanglement in residual fishing gear are not clear.

Residence time and site fidelity

Knowledge regarding habitat associations and movement patterns of fishes has historically been used as a tool for efficient exploitation (e.g.,Parrish, 1999; Sadovy and Domeier, 2005).The majority of tracking work performed on Goliath grouper to date has utilized conventional tags (Eklund and Schull, 2001; Pina-Amargós and González-Sansón 2009; Koenig et al. 2011; Collins, 2014). Previous acoustic monitoring studies have had restricted time frames, a low number of acoustically tagged individuals or a small number of monitored sites (Eklund and Schull, 2001; Frias-Torres et al., 2007; Mann et al., 2009). Although the nature of these studies limited the ability to detect fine scale behavioral patterns, all indicated high site fidelity for this species throughout its ontogeny (Eklund and Schull 2001; Frias-Torres et al., 2007; Koenig et al., 2007).

Benthic reef fishes are often sedentary with restricted home ranges (Sale 1978, Topping et al. 2005; Bryars et al., 2012), and this has been noted repeatedly among groupers (e.g., *Epinephelus striatus*, Bardach 1958; *E. guttatus*, Shapiro et al., 1994; *Plectropomus leopardus*; Zeller 1997; *E. tauvina*, Kaunda-Arara and Rose, 2004; *Mycteroperca microlepis*, Kiel 2004; *E. marginatus*, Afonso et al., 2011), so the high residence of Goliath grouper observed during this study was not surprising. Individuals maintained consistent daily presence at the same site for up to 737 days (mean = 242 days). Consistent association with home sites by mobile fishes may be maintained for access to shelter (Samoilys, 1997; Arendt et al., 2001), potential mates (Colin, 1982; Munoz et al., 2010) and foraging opportunities (Afonso et al., 2012).

Goliath grouper juveniles emigrate from inshore nurseries after reaching approximately ~ 1 m TL (Koenig et al., 2007), and maturation occurs between 110 and 140 cm TL (Bullock et al., 1992). The length of time between leaving the estuary and recruiting to offshore reef habitats is not known, but it appears that once settled, Goliath grouper maintain strong site fidelity as adults. Typical daily behavior was consistent with that of a site-attached, relatively sedentary organism

inhabiting a small core area; however, individuals did exhibit forays away from home sites that lasted for up to 16 months. Foray destinations were generally unidentified (although there were multiple observations of individuals moving between monitored sites within the study array), but it is likely that animals perform excursions to assess surrounding habitat quality or resource availability (Zeller, 1997; Lowe et al., 2009; Lowe 2009). Forays showed no relationship to season or fish size, except for a concerted seasonal departure that occurred during the spawning season.

Large groupers present an interesting management challenge (Sadovy de Mitcheson et al., 2008) as many species form large spawning aggregations far from their typical residence (gag *Mycteroperca microlepis*, McGovern et al., 2005; Coleman et al., 2012; Nassau grouper *E. striatus*, Starr et al., 2007; squaretail grouper *Plectropomus areolatus*, Hutchinson and Rhodes 2010). Goliath grouper also form spawning aggregations (Sadovy and Eklund, 1999), and individuals have been reported to travel hundreds of kilometers to reach aggregation sites (Koenig et al., 2011). The capacity to move extensive distances has implications for the consideration of marine reserves or protected areas as management tools for such mobile species, if individuals are unlikely to maintain residence within refuges throughout the year (Coleman et al., 2011; Sadovy de Mitcheson et al., 2013). Further data is needed regarding the genetic structure of the population in order to determine extent of connectivity of Goliath grouper between regions, but long distance movements of even a small number of adults may facilitate genetic exchange within the population as has been suggested for other reef species (e.g., mutton snapper *Lutjanus analis* Shulzitski et al 2009).

During this study, there was a concerted seasonal departure of mature-sized individuals during the spawning season (July – September). Although the destination and activities of individuals during this period could not be positively identified (with the exception of one individual that travelled to a suspected spawning site 174 km south of the study array and another that travelled 26 km between sites within the study array), the timing coincidence with the reproductive period (Bullock et al., 1992) is strongly indicative of a spawning migration. Eklund and Schull (2001) also noted a departure of adult Goliath grouper from a nearshore site in southwest Florida during the spawning season. As part of another study at a known spawning site, they reported that although some tagged fish left in September or October, the majority of fish acoustically tagged remained at that site past the end of the spawning season, suggesting permanent residence at the spawning site for some individuals. These individuals were all classified as adults but total lengths were not reported so it is not known whether the same size-specific pattern was observed. These mixed observations are similar to the data reported herein and indicate that some fish may remain present year round at aggregation sites while others are transient and travel long distances to reach spawning aggregations.

Interestingly, size distributions of fish recorded during visual surveys in the current study did not demonstrate a lack of large individuals within the study array during the spawning months. It is possible that the visual surveys simply did not occur often enough to capture significant differences in size across months. Alternatively, some large fish may stay where they are to spawn or simply may not spawn every year. This has also been observed for cod *Gadhus morhua* (Nielsen et al., 2013) and winter flounder *Pseudopleuronectes americanus* (DeCelles and Cadrin, 2010). Behavioral plasticity in reproduction related movement likely is an adaptive strategy and individual variability in movement should increase mixing of fishes typically segregated

throughout the rest of the year (e.g., Colin, 1992; Zeller 1998, Bolden 2000, Marino et al. 2001; Afonso et al., 2009).

Distances moved and rates of movement

During this study, most Goliath grouper maintained very small core activity spaces, but long distance movements were also recorded (up to 174 km). Eklund and Schull (2001) also reported Goliath grouper recaptures 16 – 153 km from tagging sites, and Pina-Armagos & Gonzalz-Sanson (2009) reported movements up to 168 km for two large individuals (150 – 180 cm TL) in Cuba. Recent work by Koenig and Coleman (2013) has demonstrated that individuals along the east coast of Florida will travel over 400 km to reach spawning aggregation sites. These data are important considerations in the development of protective measures, since fish are capable of moving between regions and thus have relatively large home ranges overall, which might indicate the potential for mixing between stocks.

Fish total length did not have an effect on rates of movement over the scales examined herein. Individuals (122 – 202 cm; mean = 164 cm TL) were observed to move between artificial reefs at rates as high as almost 3 km/h (range = 0.52 – 2.87 k/h) (0.8m/s), and average rates of movement observed for individuals moving between sites was approximately 1.5 km/h (0.42 m/s). The ROMs calculated herein are well within the range of energy efficient swimming speeds for fishes of this size (Weihs, 1977) and although a bit slower than the predicted energy efficient speed, still suggest that most fish are taking a relatively direct path to move between sites. Direct movements between sites suggest that fish are not moving randomly (Papastamatiou et al., 2011) and are using visual, chemical or acoustic cues to orient to specific sites, and potentially operating on memory based on previous experience.

Diel and seasonal patterns in vertical movements

Goliath grouper maintained close association with the reef structure and bottom of the water column throughout the study. As opportunistic ambush predators, many groupers are typically observed under the cover of structure which provides an increased opportunity for capture of exposed prey (Thompson and Munroe 1978; Stallings, 2008). However, the extent of vertical movements within the water column corresponded with the diel period, and fish exhibited greater movement and shallower position at monitored sites during the daylight hours. Higher activity levels during the day are normal for diurnal species (e.g., tautog *Tautoga onitis* Arendt 2001; California sheephead *Semicossyphus pulcher* Topping et al., 2006; painted comber *Serranus scriba* March et al., 2010). Vertical activity of Goliath grouper was especially evident during crepuscular periods, which is currently unexplained but may correspond with increased feeding activity at dawn and dusk (Zeller 1997; Lowe et al., 2003; Meyer and Holland 2005; Gibran, 2007; March et al. 2010; Afonso et al 2012; Masuda et al., 2012).

A distinct seasonal pattern was also observed, with the lowest frequency of vertical movements during the coldest months of the year. Average depths of all individuals were the deepest during January and February. The average bottom temperature during these months ranged 14 – 20°C (mean = 18°C), while temps during the warmest months (July – September) ranged 27 - 30°C

(mean = 29°C) over the three years of this study. The thermal range of Goliath grouper is generally restricted to temperatures > 14°C (Gilmore et al. 1978), and the winter months are assumed to be a period of reduced feeding because the species becomes visibly lethargic (Collins, pers. obs) and is more difficult to catch on hook and line (Eklund and Schull 2001; Collins pers. obs.). Lower temperatures are likely to reduce metabolism of marine fishes and seasonally reduced activity during periods of low temperatures has also been noted for multiple species (e.g., tautog *Tautoga onitis*, Arendt et al., 2001; California sheephead *Semicossyphus pulcher*, Topping et al., 2006). As water temperatures began to increase in the spring (~ April), Goliath grouper vertical movement within the water column increased and average position within the water column became shallower.

Extreme vertical movements to upper portions of the water column were observed during all months, and were most common during the spring and summer months (April – September). It is hypothesized that these events may be related to feeding, either upon natural prey (baitfish; e.g. Clupeidae) or as orientation to and predation upon hooked fish being reeled in by anglers. Goliath grouper have been observed to chase hooked fish to the surface during angling activities (Collins, pers. obs.), so the detection of Goliath grouper presence in the upper portions of the water column could very likely be related to this behavior since all monitored sites are well within the reach of recreational and commercial fishers in the area. Alternately, extreme movements within the water column may be indicative of catch and release events. Additionally, mean fish position was related to site characteristics, and higher average positions within the water column were observed at sites with higher vertical relief. This further supports the idea that Goliath grouper prefer to maintain consistent association with shelter and that movement within the water column is most likely influenced by a behavioral preference to maintain contact with benthic structure.

Conclusions and need for additional work

Immediate or delayed mortality was not observed for any of the Goliath grouper that were caught and released during this study. Additionally, monitoring period was not affected by the severity of barotrauma or the length of handling time, which suggests that with proper handling, Goliath grouper are not subject to high levels of release mortality in the eastern Gulf of Mexico (at depths to 40 m). However, strong site fidelity of Goliath grouper to artificial reefs increases susceptibility to fishing pressure and amplifies interactions with anglers, so the chronic effects of repeated capture remain unclear. Additionally, further work should be performed using charter captains that release Goliath grouper without venting them to identify survival of fish that are not able to be submerged.

Acoustically tagged Goliath grouper displayed small core areas of use, maintaining consistent daily presence at specific artificial reefs for up to 736 days, but long distance movements (>175 km) demonstrated the capacity of individuals to move over broader geographic scales. The high numbers of conspecifics and the persistent long-term presence of individuals at high relief artificial reefs further demonstrated the importance of these habitats for Goliath grouper in the eastern Gulf of Mexico. The concerted departure of mature sized fish (>140 cm) during the reproductive period is suggestive of a spawning migration, although the destinations of departed

individuals during this period remain unknown. Future efforts to identify spawning aggregation sites within the eastern Gulf of Mexico are warranted.

Dissemination of Project Results

Results of the completed research should be of interest to others working on Goliath grouper, catch and release mortality, and reef systems in general. Throughout the duration of this project, a total of 17 presentations were given (seven during scientific meetings, ten to state and federal management agencies, sport dive clubs, other stakeholder groups, or the general public). These presentations are listed below. To date, one manuscript (Seyoum et al., 2013) and one PhD dissertation (Collins, 2014) have resulted in part from this work. We expect to continue to publish the findings of this research in the form of at least two additional manuscripts in peer-reviewed, scientific journals.

Publications to date

- Seyoum, S., Tringali, M.D., Barthel, B.L., Puchulutegui, C., Davis, M.C., Collins, A.B. and Craig, M.T. 2013. Isolation and characterization of 29 polymorphic microsatellite markers for the endangered Goliath grouper (*Epinephelus itajara*), and the Pacific Goliath grouper (*E. quinquefasciatus*). Conservation Genetics Resources 5: 4pp.

- Collins, A.B. 2014. An investigation into the habitat, behavior and opportunistic feeding strategies of the protected Goliath grouper (*Epinephelus itajara*). PhD Dissertation, University of South Florida, Tampa, Florida. 183 pp.

Presentations to date

- Collins, A.B. The hogfish and the Goliath: Tales of Big Fish Tails… Florida Underwater Sports, Sarasota, Florida. October 21, 2010.
- Collins, A.B. and Barbieri, L.R. A big fish story: Goliath grouper distribution and movements in the eastern Gulf of Mexico. Southern Division of the American Fisheries Society annual meeting. Tampa, Florida. January 13, 2011.
- Collins, A.B. The Great Goliath grouper Count. TRUE Dive club meeting, St. Petersburg, Florida. May 2011.
- Collins, A.B. Project description and public outreach via an educational table and video. Reef Monitoring, Inc. presentation at Saint Petersburg College. Clearwater, Florida, July 2011.
- Collins, A.B. Big fish tales: Tagging and tracking Goliath grouper in the Gulf of Mexico. Scientific Angler Seminar Series, Naples, FL. January 18, 2012.
- Collins, A.B. A great big fish tale: Long term tracking of Goliath grouper after catch and release events. FISH annual meeting, Melbourne, Florida. June 1, 2012.
- Collins, A.B. A great big fish tale: Long term tracking of Goliath grouper after catch and release events. American Fisheries Society annual meeting. August 2012. Minneapolis/St. Paul, Minnesota.
- Collins, A.B., Barbieri, L.R. and Motta, P.J. Florida Chapter of the American Fisheries Society annual meeting: One fish, two fish, where's that huge fish? Long-term tracking of Goliath grouper after catch and release. Altoona, Florida, February 19 – 21, 2013.

- Collins, A.B., Barbieri, L.R. and Motta, P.J. Ad-Hoc Goliath grouper Joint Steering Committee Science Workshop: FWC Goliath grouper program: Research Update. Gulf of Mexico Fishery Management Council Office, Tampa, Florida, March 12, 2013.
- Collins, A.B., Barbieri, L.R. and Motta, P.J. FWC Seminar Series: One fish, two fish, where's that huge fish? Long-term tracking of Goliath grouper after catch and release. Invited speaker. Eustis, Florida, March 29, 2013.
- Collins, A.B and Barbieri, L.R. State of our Reefs Symposium: Goliath grouper research at FWC. St. Petersburg College, Clearwater, Florida. April 4, 2013.
- Collins, A.B., Barbieri, L.R. and Motta, P.J. American Society of Ichthyologists and Herpetologists annual meeting: Behavior and long-term movement patterns of Goliath grouper after catch and release. Albuquerque, NM, July 11 – 16, 2013.
- Collins, A.B., Barbieri, L.R. and Motta, P.J. F.I.S.H annual meeting: Size matters! Habitat relief, volume and structural complexity are predictors of Goliath grouper presence and density in the Gulf of Mexico, November 11, 2013.
- Collins, A.B. University of Tampa, invited seminar speaker. One fish, two fish, where's that huge fish? A goliath research project. November 15, 2013.
- Collins, A.B. Great American Teach-In, West Orange High School. One fish, two fish…where's that huge fish? November 22, 2013.
- Collins, A.B. Clearwater Christian College, invited seminar speaker. One fish, two fish, where's that huge fish? A goliath research project. March 4, 2014.
- Collins, A.B. FWC/FWRI: USF PhD dissertation defense. An Investigation into the Habitat, Behavior, and Opportunistic Feeding Strategies of the Protected Goliath Grouper, *Ephinephelus itajara*. March 25, 2015.

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Tables and Figures

Table 1. Characteristics of artificial reef sites (shipwrecks; Fig.2) acoustically monitored 2011 through 2013. The depth, maximum vertical relief, volume, and area are listed for each reef, as well as the number of deployed acoustic receivers (VR2s) and number of acoustically tagged Goliath grouper (tags) at each site. The mean number of Goliath grouper *Epinephelus itajara* observed during visual surveys over a 5 year period (Collins, 2014) is indicated seasonally for each site (number of surveys per season for each site is indicated in parentheses). The six primary sites are indicated by asterisks (P1 – P6), and were surveyed seasonally 2008 – 2009, sporadically in 2010, and at least every other month 2011 – 2013. The remaining accessory sites (A1 – A6) were surveyed opportunistically throughout the study period.

							Mean number of Goliath grouper observed 2008 – 2013 (*survey n*)			
Site	Depth (m)	Relief (m)	Vol (m^3)	Area (m^2)	VR2 (n)	Tag (n)	winter	spring	summer	fall
P1*	13	4.57	432	95	2	3	4.2 (11)	2.4 (14)	2.3 (8)	3.2 (9)
P2*	19	1.68	854	510	4	11	6.5 (11)	9.9 (18)	9.2 (18)	6.8 (12)
P3*	19	3.05	3853	1264	3	0	1.5 (6)	1.5 (16)	1.3 (14)	1.5 (8)
P4*	26	7.62	10401	1365	4	9	10.1 (8)	12 (14)	13.9 (17)	11.4 (13)
P5*	30	11.75	1670	142	3	8	9.0 (7)	9.9 (14)	11.9 (13)	9.9 (8)
P6*	32	3.05	507	166	2	1	4.3 (8)	4.5 (10)	7.1 (10)	3.73 (11)
A1	12	2.74	765	279	1	1	Na (0)	3 (2)	Na (0)	1 (1)
A2	21	4.88	4828	990	1	2	Na (0)	3.8 (4)	4 (1)	3 (2)
A3	24	3.66	413	113	1	0	0 (1)	1.7 (3)	1.8 (4)	2.3 (4)
A4	26	2.44	1554	638	1	0	4.33 (3)	3.25 (4)	5 (5)	2 (3)
A5	34	5.18	881	170	1	2	3.3 (4)	4.5 (6)	11.2 (10)	4.5 (4)
A6	39	10.25	18288	2000	2	2	9.7 (3)	9 (1)	23.4 (5)	12 (2)

Table 2. Acoustically monitored Goliath grouper *Epinephelus itajara*. Headings indicate tagging site depth, fish ID, total length (TL), barotrauma (BT), handling time (HT), tag date, date of last detection, total monitoring period (TMP), total days detected at tagging site (DTS), total days detected at other sites (DOS), number of sites detected, number of absences exceeding 7 days (Sites/forays), maximum distance between sites of detection (Max dist), and whether there was a departure during spawning season (Yes indicates a departure each spawning season that the fish was within the array; Year 2 indicates a departure only during the second year of monitoring but not during the first year; NA indicates the fish was not in the array).

Tag Site (m)	ID	TL (cm)	BT	HT (min)	Tag date	Last detection	TMP (days)	DTS (days)	DOS (days)	Sites/ forays	Max dist (km)	Seasonal depart?
A1 (10)	5779	192	1	10	5/3/12	11/18/13	565	227	9	2/4		Yes
P1 (13)	85	172	1	11	4/26/11	4/15/13	721	14	4	3/0		NA
	5766	122	1	3	6/29/11	1/22/13	574	112	1	2/5	11.4	No
	5775	130	1	7	8/16/11	9/22/11	38	32	0	1/0	0	No
P2 (19)	79	150	2	14, 1	4/13/11	3/25/13	713	467	3	2/5	11.4	Yes
	80	181	2	14, 7	4/13/11	8/1/12	477	354	2	3/9	11.4	Yes
	86	157	2	8	4/26/11	4/14/13	720	170	7	3/10	17.3	Yes
	87	180	1	6	4/27/11	4/25/13	730	318	4	3/6	148.5	Yes
	88	150	1	6, 7	4/27/11	1/12/13	627	487	0	1/0	0	Year 2
	90	205	1	9	4/27/11	6/15/11	50	50	0	1/0	0	NA
	5768	141	1	3	7/6/11	3/13/13	617	188	38	3/4	41.3	No
	5769	134	2	5	7/6/11	6/18/13	714	532	26	5/6	25.8	Year 2
	5770	148	2	5	7/6/11	7/12/13	738	490	3	5/12	11.4	Year 2
	5771	150	2	9	7/6/11	7/5/12	366	48	47	2/1	7.4	Yes
	5773	105	2	5	8/12/11	8/17/13	737	737	0	1/0	0	No
A2 (20)	139	146	1	12	9/20/12	3/7/13	169	12	97	2/4	7.4	NA
	5785	141	1	5	9/20/12	11/7/13	414	414	0	1/0	0	No
P4 (25)	81	149	2	11	4/14/11	9/17/11	157	111	26	2/1	29.6	Yes
	82	182	2	10,12	4/14/11	11/18/13	950	461	0	1/2	U	Yes
	89	150	1	5	4/14/11	7/2/11	80	80	0	1/0	0	NA
	5761	196	2	16	6/9/11	7/9/11	31	31	0	1/0	0	Yes
	5762	186	2	7	6/9/11	6/15/13	738	550	8	4/6	29.6	Yes
	5763	174	2	8	6/9/11	3/14/13	645	271	1	2/2	11.3	Yes
	5764	196	2	5,10	6/9/11	6/15/13	738	577	2	2/3		Yes
	5774	206	2	10	8/16/11	5/14/12	273	226	0	1/1	U	Yes
	138	176	2	13	8/9/12	12/5/12	119	7	45	2/1	7.1	Yes

P5 (30)	83	175	2	12	4/19/11	5/6/11	18	18	0	1/0	0	NA
	84	181	2	14	4/19/11	5/3/12	381	336	0	1/1	U	Yes
	91	202	3	32	5/10/11	1/9/13	611	119	22	3/9	173.5	Yes
	92	155	1	5	5/10/11	8/20/11	104	103	1	2/1	26.3	Yes
	93	134	1	4	5/10/11	2/28/12	295	183	67	2/3	22.1	No
	5765	145	2	6	6/16/11	10/20/11	127	127	0	1/0	0	No
	5782	175	3	12	7/3/12	6/11/13	344	192	6	3/3	26.3	Yes
	5783	163	2	9	7/3/12	11/18/13	504	280	9	3/11	27.3	Yes
P6 (32)	140	195	3	62	12/6/12	11/18/13	348	180	12	4/8	19.2	Yes
A5 (34)	5777	135	3	8	9/29/11	9/2/12	340	339	0	1/0	0	Year 2
	5778	146	3	11	9/29/11	9/24/13	727	168	1	2/4	4.9	No
A6 (39)	5767	188	3	9	7/20/11	8/11/12	389	141	0	1/5		Yes
	5772	168	3	9,19	7/20/11	8/29/12	407	275	0	1/1		Yes

Table 3. Seasonal departures of acoustically tagged Goliath grouper *Epinephelus itajara* observed during their spawning season (June – September) for all three years of the study. The number of Goliath grouper that departed is displayed as a percentage of the total number of acoustically tagged present within the array during this period. The date range of departure indicates the time frame during which individuals departed; days at large indicates the number of days that the individuals were gone from their 'home' sites, and the number of fish that returned is indicated as a percentage of the total number of fish that departed.

Year	*n* departed/ *n* present (% departed)	Date range of departure (mean)	Days at large (mean)	*n* returned/ *n* departed (% return)
2011	18/26 (69%)	6/15/11 – 9/15/11 (8/11/11)	18 – 304 (94)	14/18 (78%) to array; 13/18 (72%) to original tag site
2012	20/22 (91%)	6/1/12 – 9/2/12 (8/1/12)	18 – 183 (93)	14/22 (64%) to array; 12/22 (55%) to original tag site
2013	7/9 (78%)	7/12/13 – 8/29/13 (8/3/13)	70 – 119 (95)	4/7 (57%) to original tag site

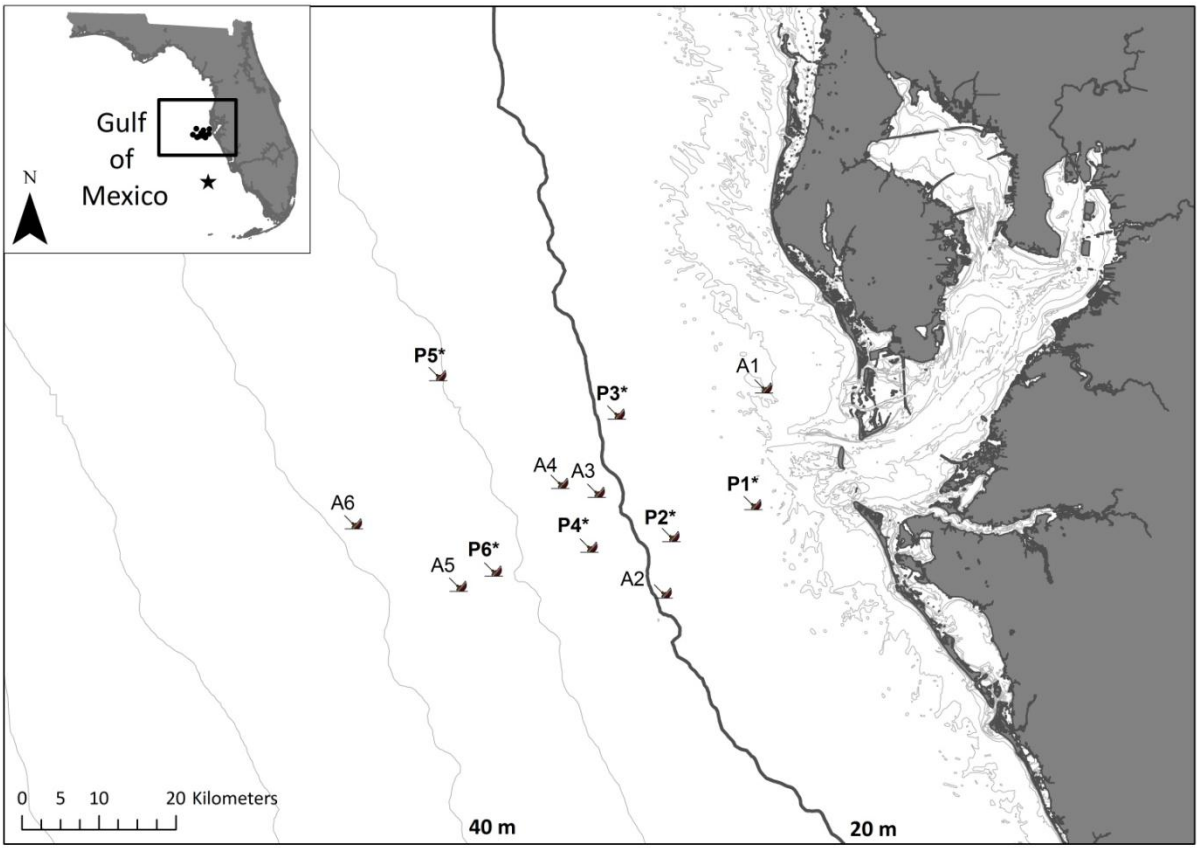

Fig. 1. Map of study area and sites of receiver (Vemco VR2W) deployment. Inset indicates the study array as well as an additional receiver (star) deployed briefly by another research group approximately 175 km south of the study area that detected 2 tagged individuals in 2011. Primary sites are in bold and indicated by asterisks.

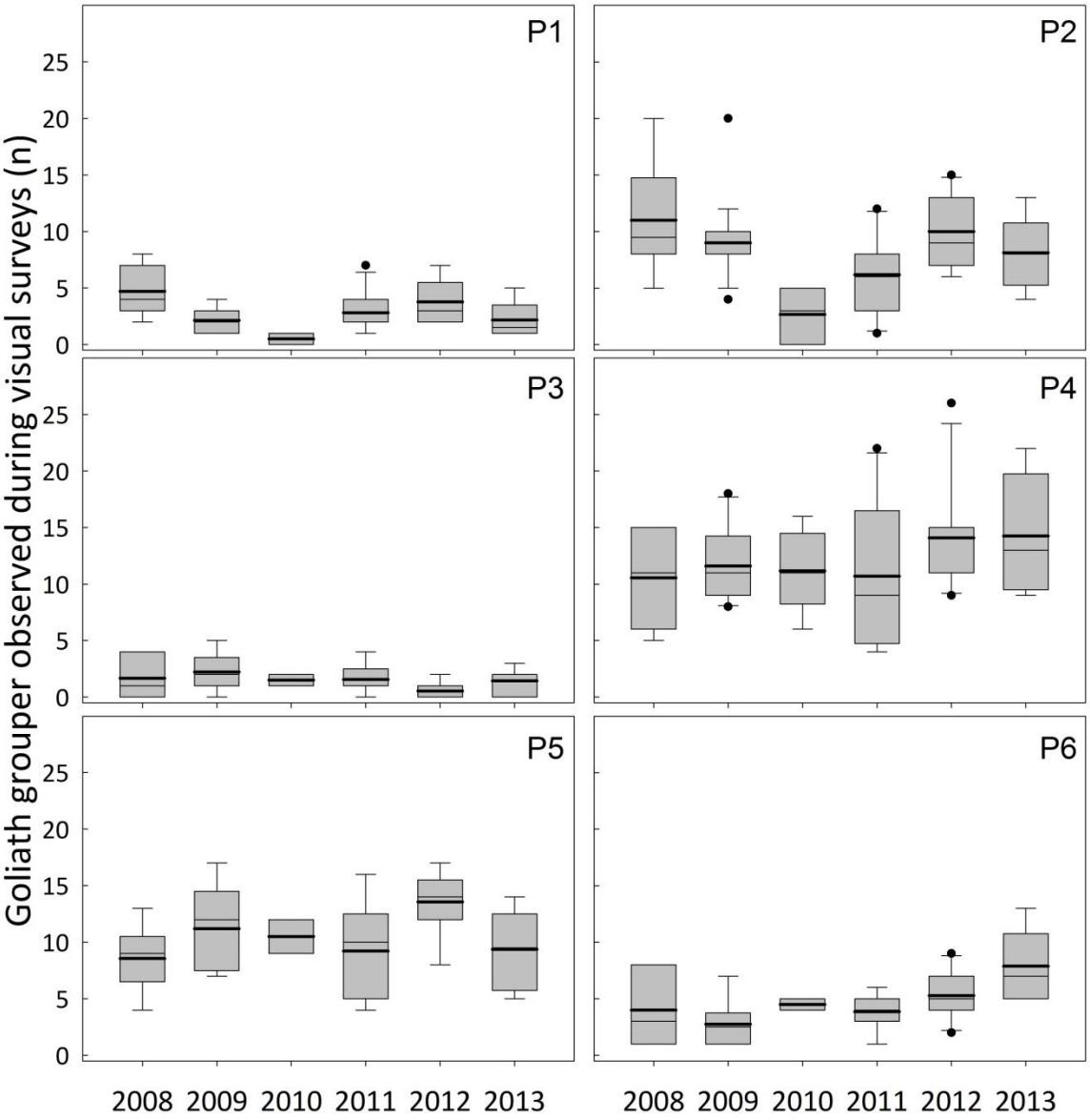

Fig. 2. Number of Goliath grouper *Epinephelus itajara* observed at each of the six primary sites (site characteristics are described in Table 1) during visual surveys from 2008 – 2013 (adjusted from Collins, 2014). Box plots indicate the 25 – 75 quartiles, whiskers indicate 95% confidence intervals, and observations falling outside of the 95% confidence intervals are indicated by (●). The mean and median are indicated by the bold and thin horizontal lines, respectively.

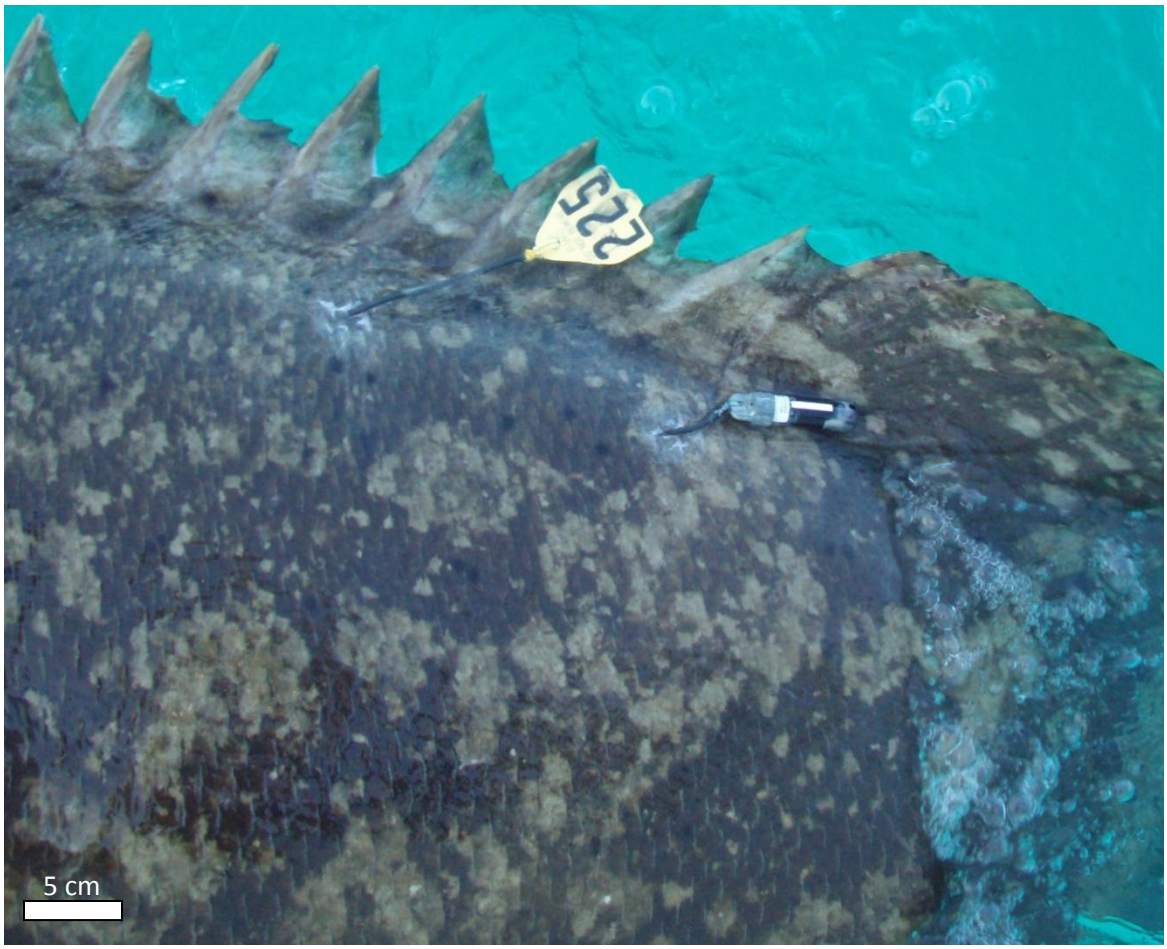

Fig. 3. Conventional identification tag (anterior) and acoustic transmitter (posterior) externally attached beneath the dorsal fin of an Goliath grouper *Epinephelus itajara* prior to release.

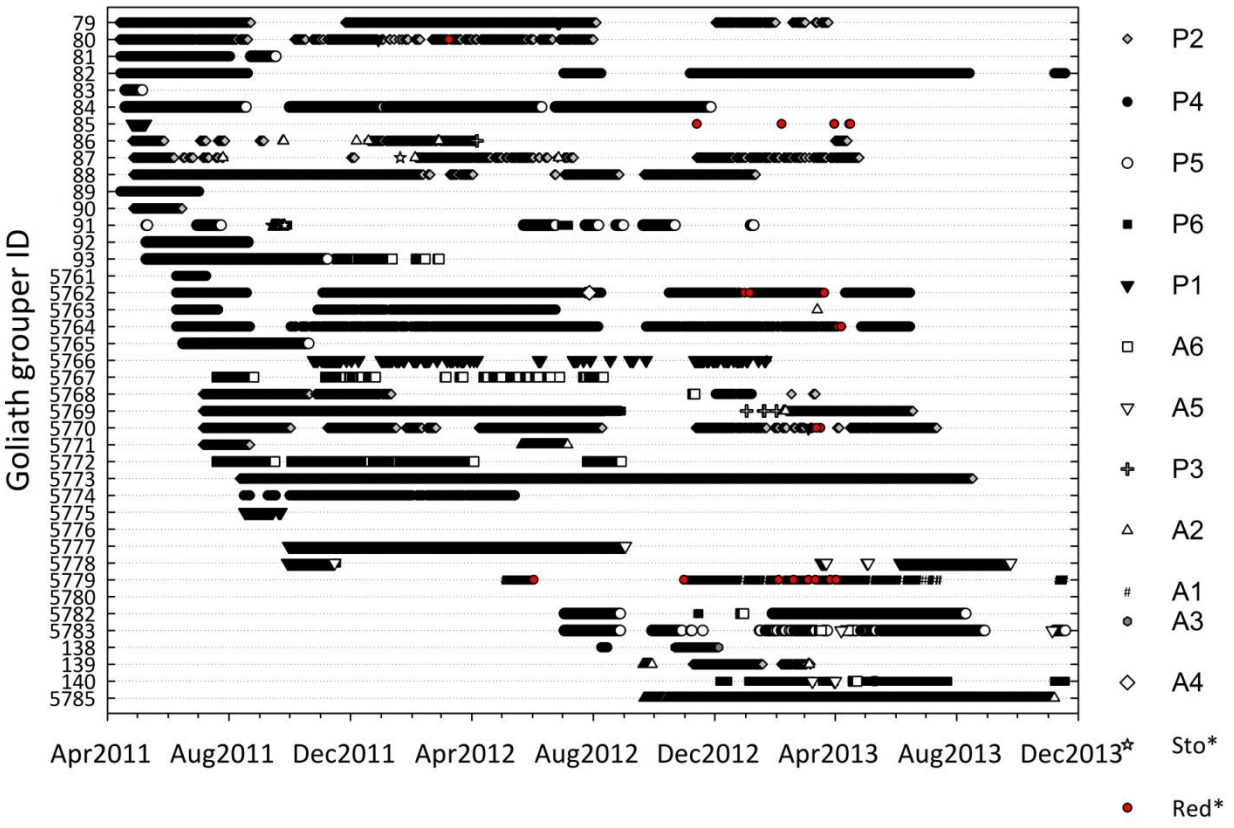

Fig. 4. Daily presence at monitored sites within the study area for 39 acoustically tagged Goliath grouper *Epinephelus itajara* between April 2011 and December 2013. Goliath grouper tag ID is indicated along the y-axis. Symbols represent presence at specific artificial reefs monitored during this study (as described in Table 1) plus 2 additional sites (*) being monitored by different research groups within the study area.

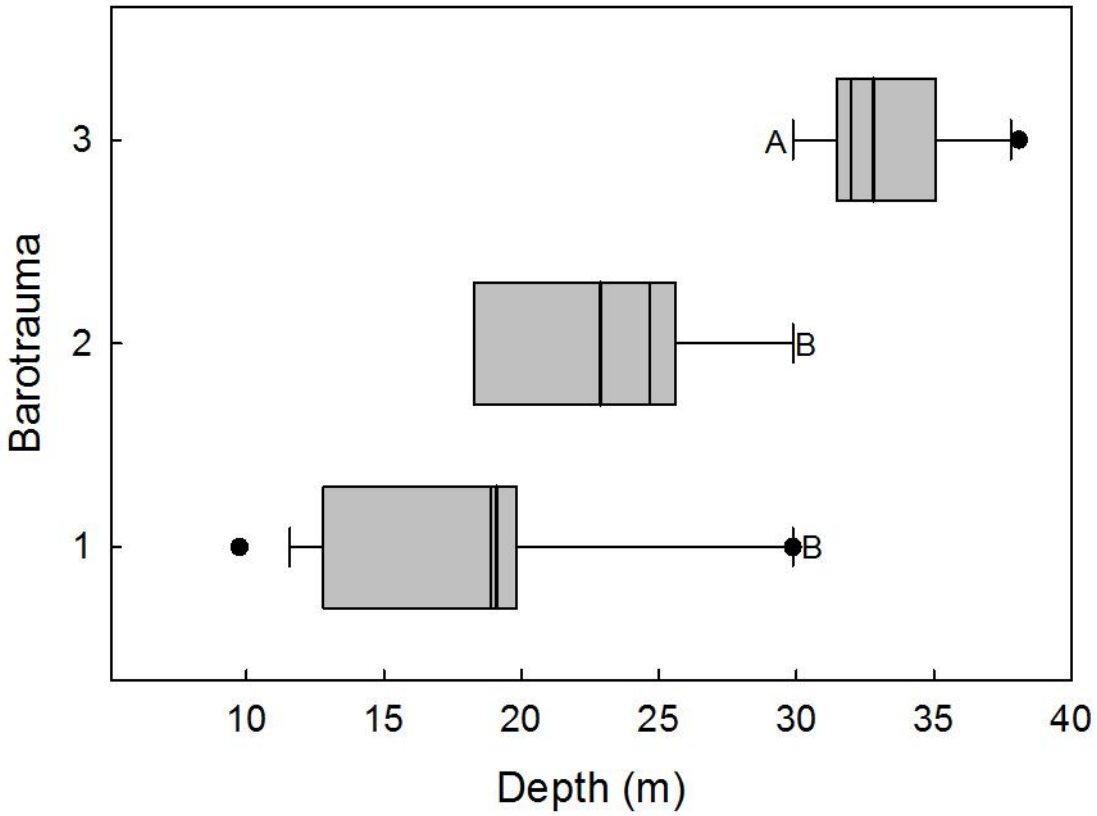

Fig. 5. Barotrauma (BT) values for Goliath grouper, *Epinephelus itajara*, by depth of capture. BT values were assigned qualitatively after a visual inspection as minimal (1), moderate (2) or severe (3). Severity was significantly higher ($p < 0.001$; Kruskal-Wallis One Way Anova) at capture depths greater than 30 m. Box plots indicate the 25 – 75 quartiles, whiskers indicate 95% confidence intervals, and observations falling outside of the 95% confidence intervals are indicated by (●). The mean and median are indicated by the bold and thin horizontal lines, respectively. Letters denote significant differences between groups.

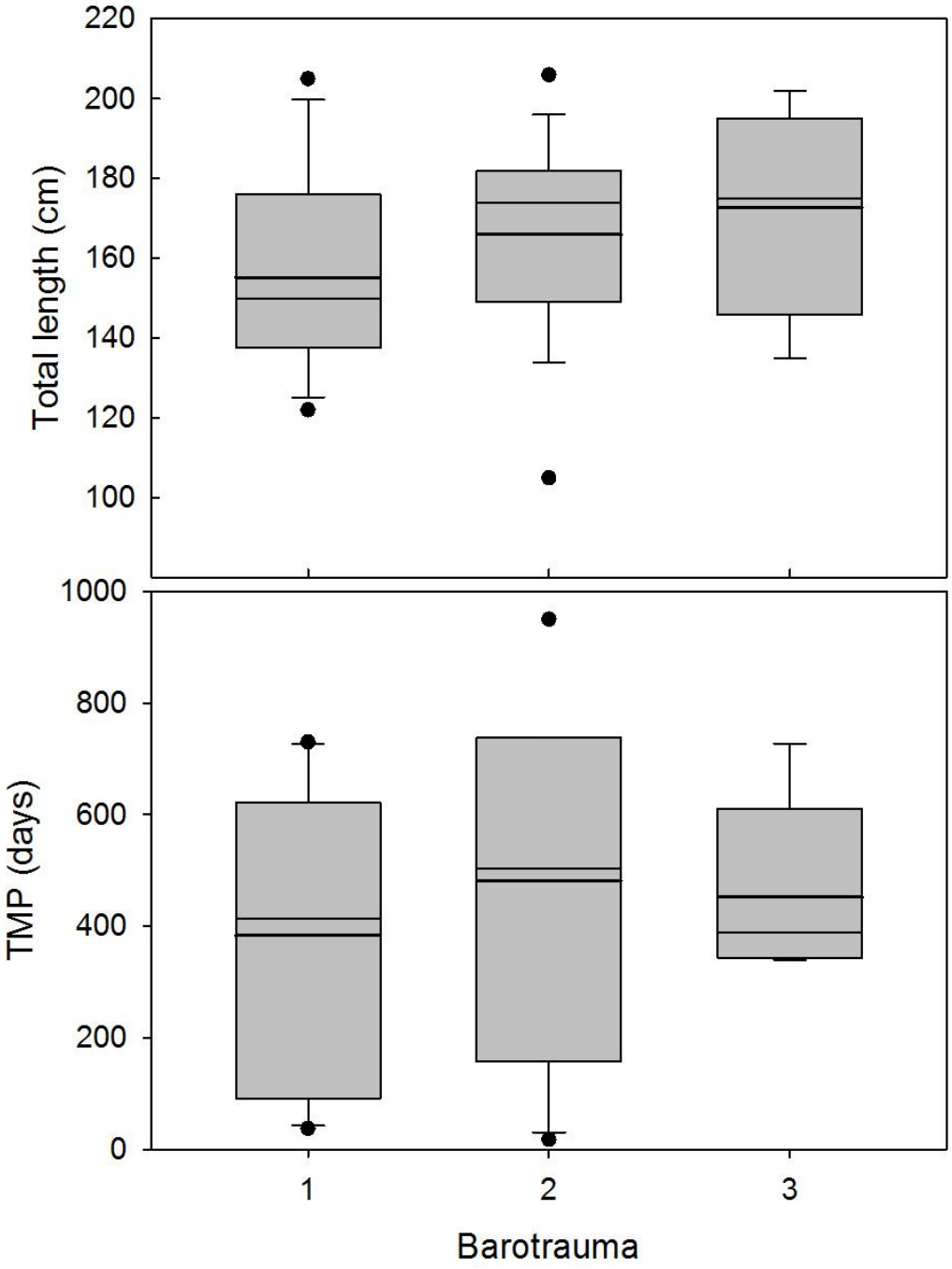

Fig. 6. Total length (top) and total monitoring period (TMP, bottom) of Goliath grouper, *Epinephelus itajara*, experiencing minimal (n=13), moderate (n=19) or extreme (n=7) barotrauma (1 – 3, respectively). There was no relationship between TL (p = 0.288) or TMP (p = 0.536) between barotrauma groups (Kruskal-Wallis One Way ANOVA). Box plots indicate the 25 – 75 quartiles, whiskers indicate 95% confidence intervals, and observations falling outside of the 95% confidence intervals are indicated by (●). The mean and median are indicated by the bold and thin horizontal lines, respectively.

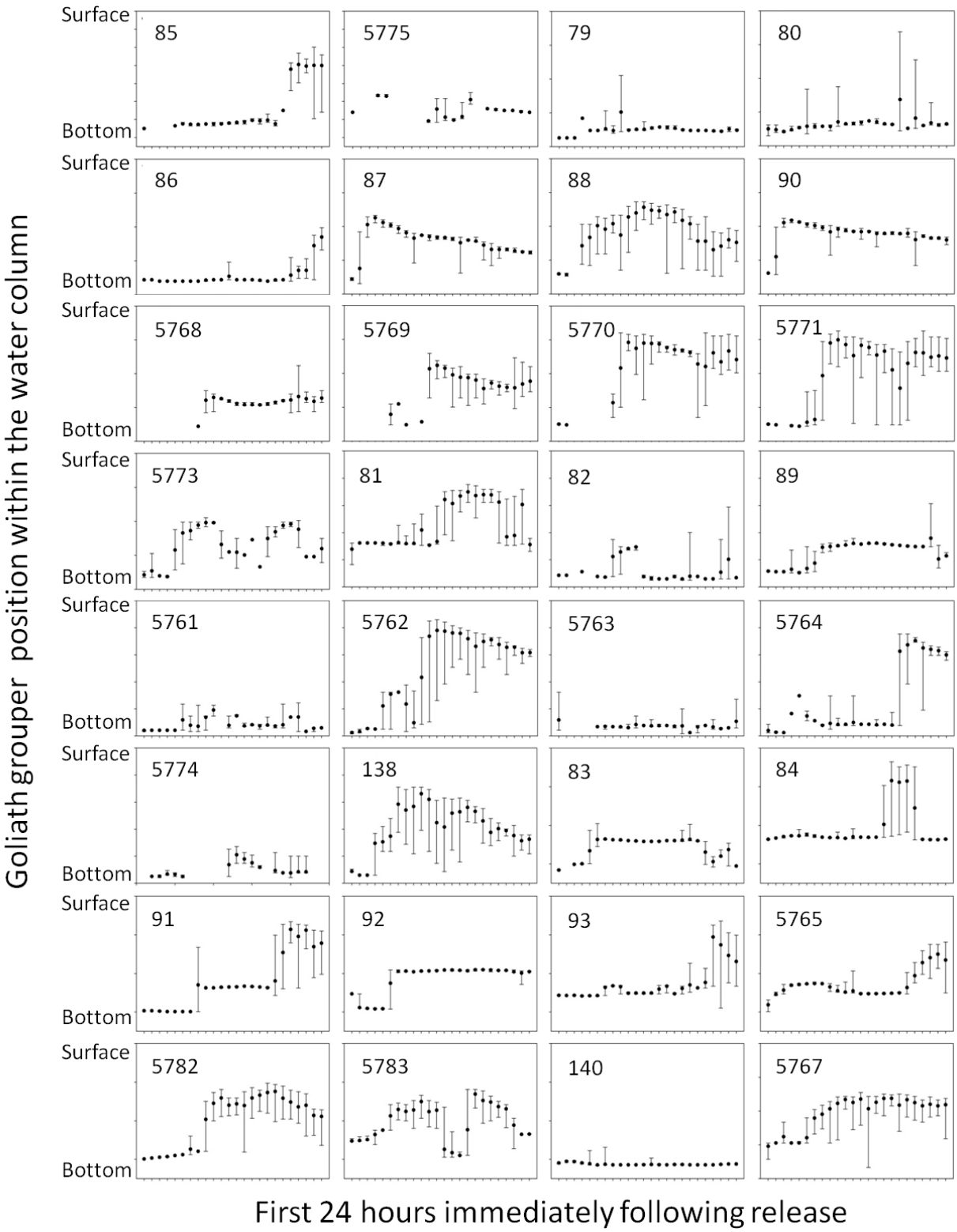
Goliath grouper position within the water column
Surface
Bottom
85
5775
79
80
86
87
88
90
5768
5769
5770
5771
5773
81
82
89
5761
5762
5763
5764
5774
138
83
84
91
92
93
5765
5782
5783
140
5767
First 24 hours immediately following release

Fig. 7. Hourly depth position (y-axes) of each individual Goliath grouper, *Epinephelus itajara*, tagged at one of the 6 main sites for the first 24 hours (x-axes) after catch and release. Error bars indicate the minimum and maximum depth of the fish for that hour. Individuals are arranged in order of increasing capture depth. Details for each individual are available in Table 2.

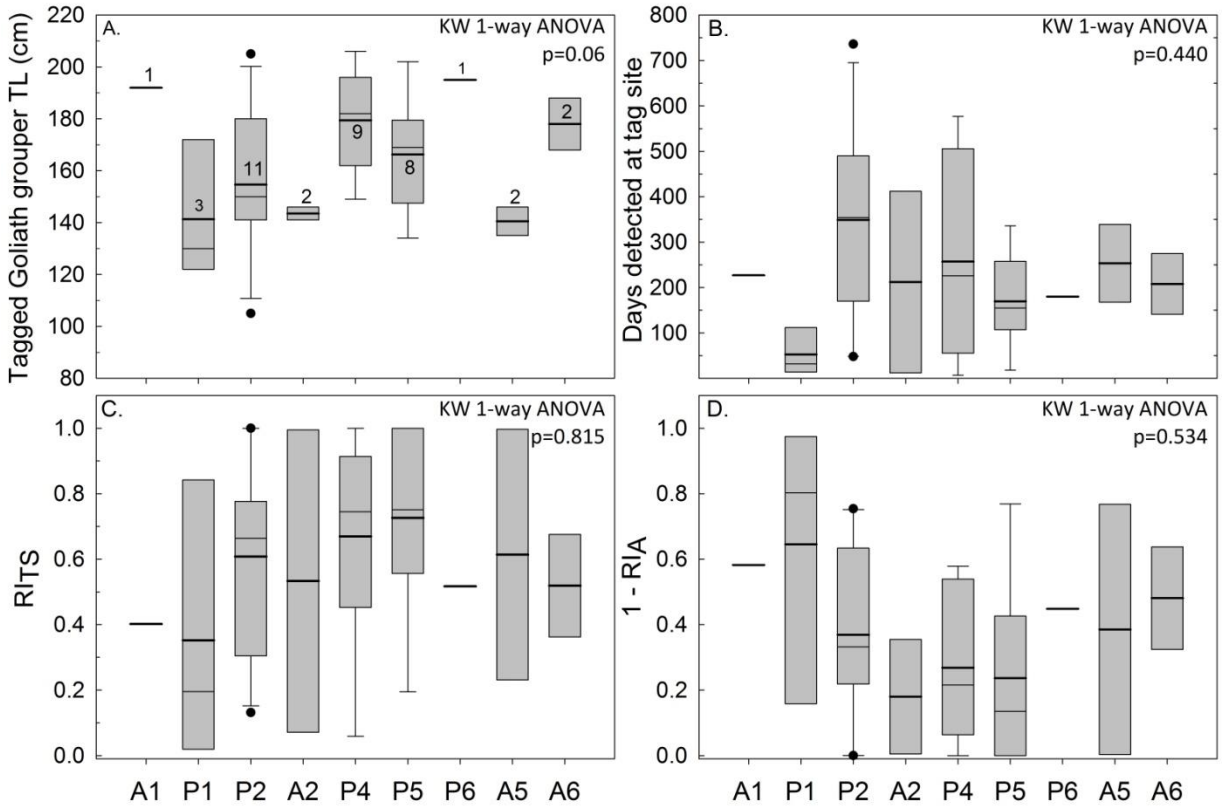

Fig. 8. Data for acoustically tagged Goliath grouper, *Epinephelus itajara*, for each tagging site within the study array by (A) total length (the number of fish tagged per site is indicated for each box), (B) the total number of days detected at the site of tagging, (C) the residence index at tag site (RI_{TS}) and (D) the total time fish were unaccounted for (1 – residence index within the array, RI_A where 1 = 100% presence). Sites are listed in order of increasing depth (10 – 40 m) along the x-axis. There were no significant differences among sites for any of these 4 variables (Kruskal-Wallis one-way ANOVA). Box plots indicate the 25 – 75 quartiles, whiskers indicate 95% confidence intervals, and observations falling outside of the 95% confidence intervals are indicated by (●). The mean and median are indicated by the bold and thin horizontal lines, respectively.

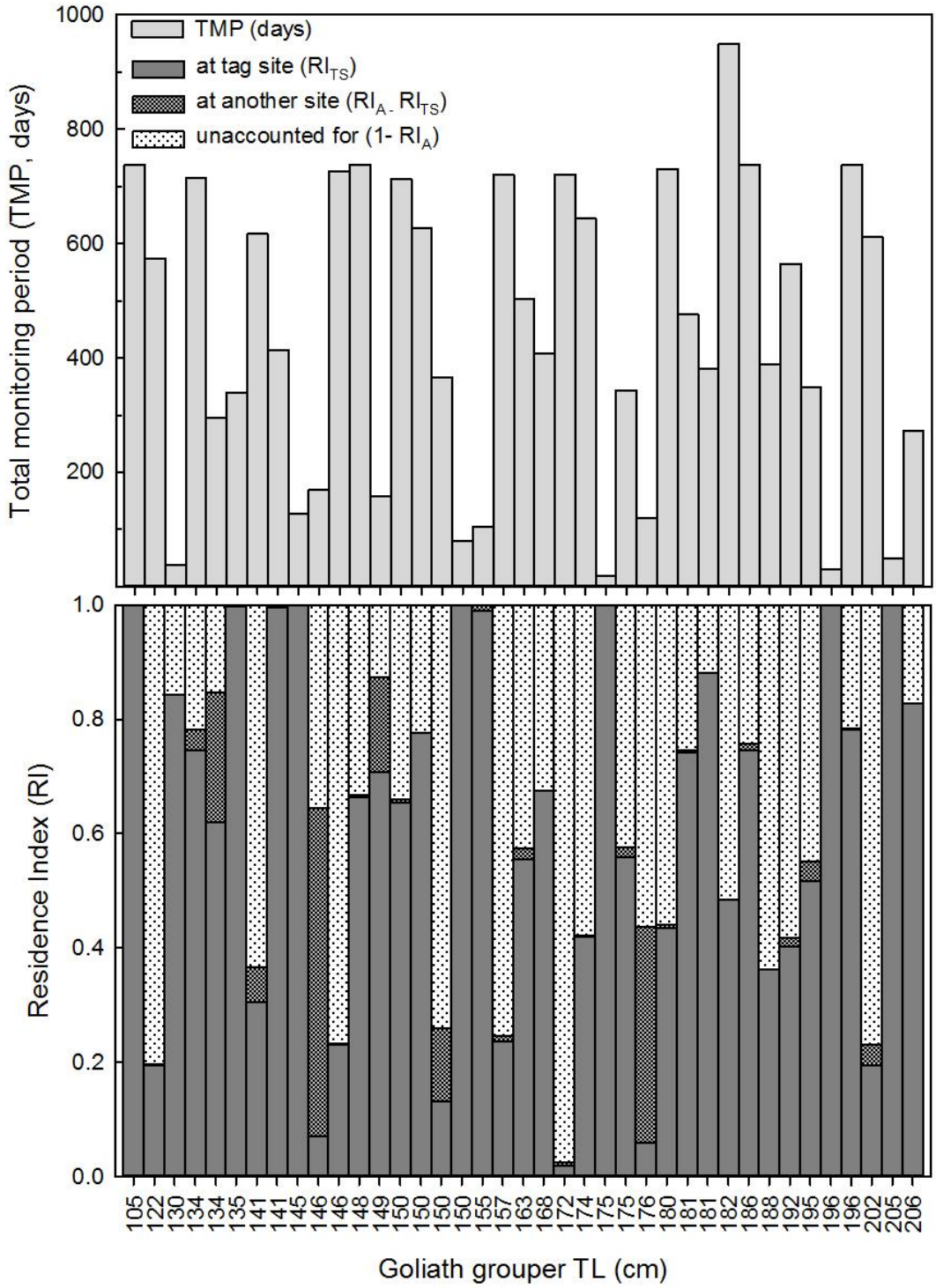

Fig. 9. Total monitoring period and residence indices for 39 acoustically tagged Goliath grouper *Epinephelus itajara*. Individuals are arranged by total length, as indicated on the x-axis. Pearson correlation indicated that TL did not affect TMP ($p = 0.773$), RI_{TS} ($p = 0.713$) or time unaccounted for ($1 – RI_A$; $p = 0.449$).

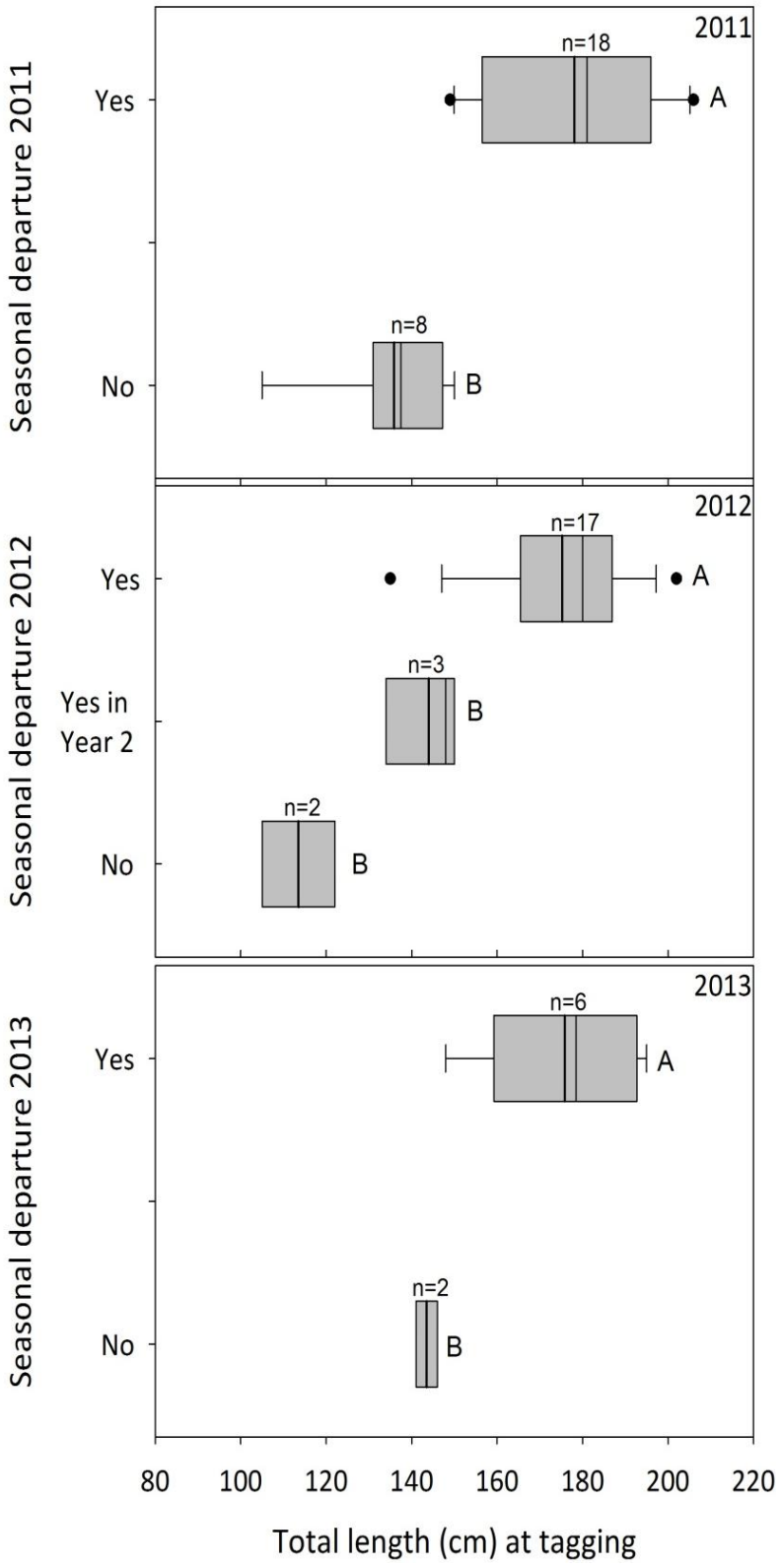
2011
n=18
Yes
A
n=8
No
B
Seasonal departure 2011
2012
n=17
Yes
A
n=3
Yes in
Year 2
B
n=2
No
B
Seasonal departure 2012
2013
n=6
Yes
A
n=2
No
B
Seasonal departure 2013
80
100
120
140
160
180
200
220
Total length (cm) at tagging

Fig. 10. Size distribution of Goliath grouper *Epinephelus itajara* that exhibited a seasonal departure during spawning season ('Yes') or maintained continuous presence at resident sites ('No'). Total lengths were measured at initial capture. Letters denote significant differences ($p<0.001$, ANOVA) between groups and the number of individuals within each group is indicated above each box. Box plots indicate the 25 – 75 quartiles, whiskers indicate 95% confidence intervals, and observations falling outside of the 95% confidence intervals are indicated by (●). The mean and median are indicated by the bold and thin horizontal lines, respectively.

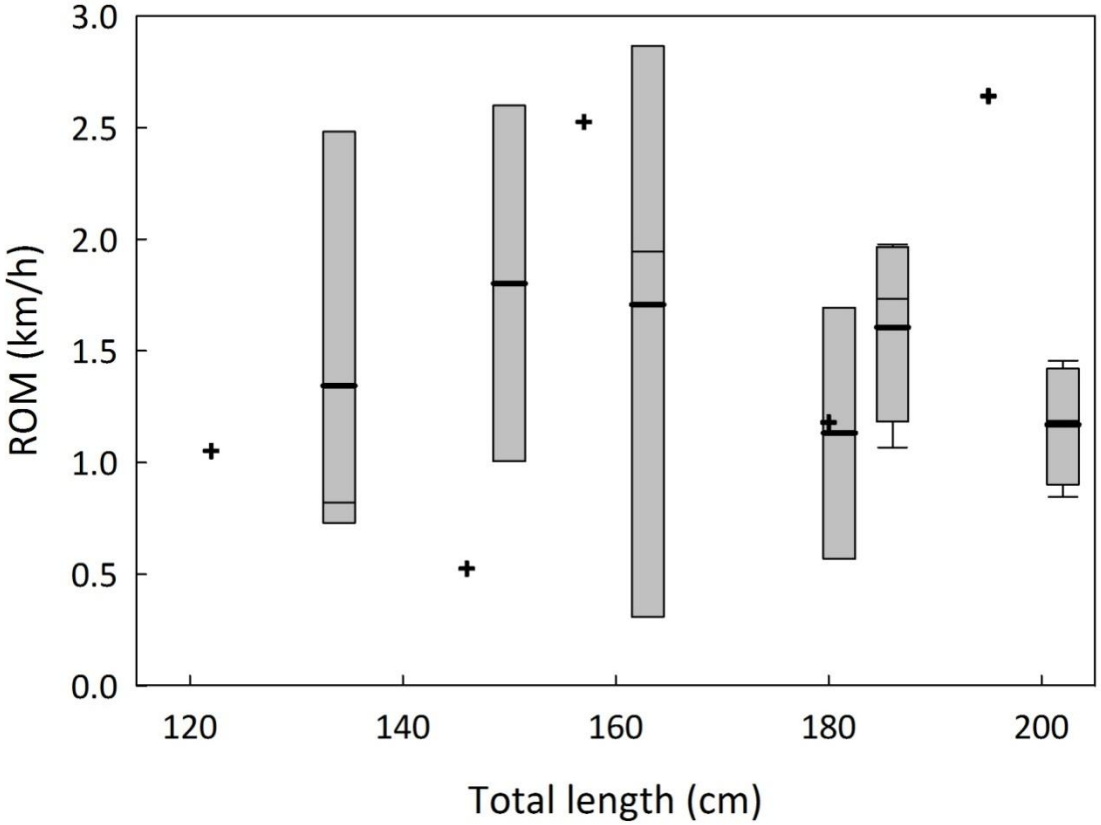

Fig. 11. Rates of movement (ROM) for Goliath grouper *Epinephelus itajara*, moving between sites within the study array inside of a 24 hour period (n=11 individuals). Individuals that exhibited multiple movements that allowed for ROM calculations are indicated by boxes (mean and median values are displayed as the bold and thin horizontal lines within each box). Individuals for which only one ROM was calculated are indicated by (+) ROMs are reported by fish total length (TL, cm). There was no significant difference among individual ROMs ($p = 0.248$), and ROM was not related to fish TL ($p = 0.896$). Box plots indicate the 25 – 75 quartiles, whiskers indicate 95% confidence intervals, and observations falling outside of the 95% confidence intervals are indicated by (●). The mean and median are indicated by the bold and thin horizontal lines, respectively.

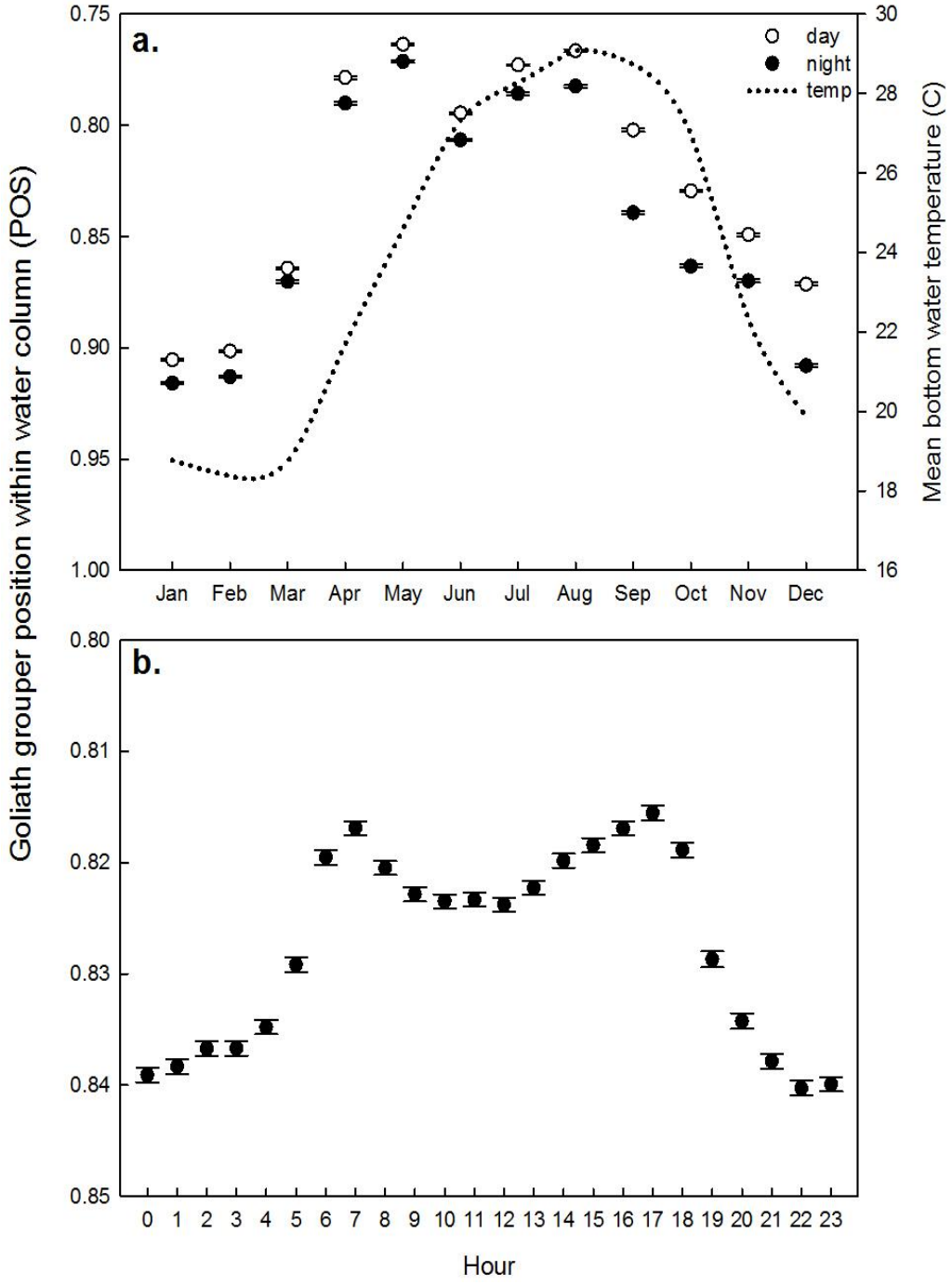

Fig. 12. (a.) Mean monthly position within the water column during the day (05:01 – 18:59 EST) and night (19:00 – 05:00 EST) and (b.) mean hourly position over all months (EST) of acoustically monitored. Goliath grouper *Epinephelus itajara* (n=39). Position is standardized across sites by dividing fish depth by the maximum depth of the site, such that a position of 1.00 corresponds to the bottom and 0.0 corresponds to the surface. Error bars indicate 95% confidence limits.

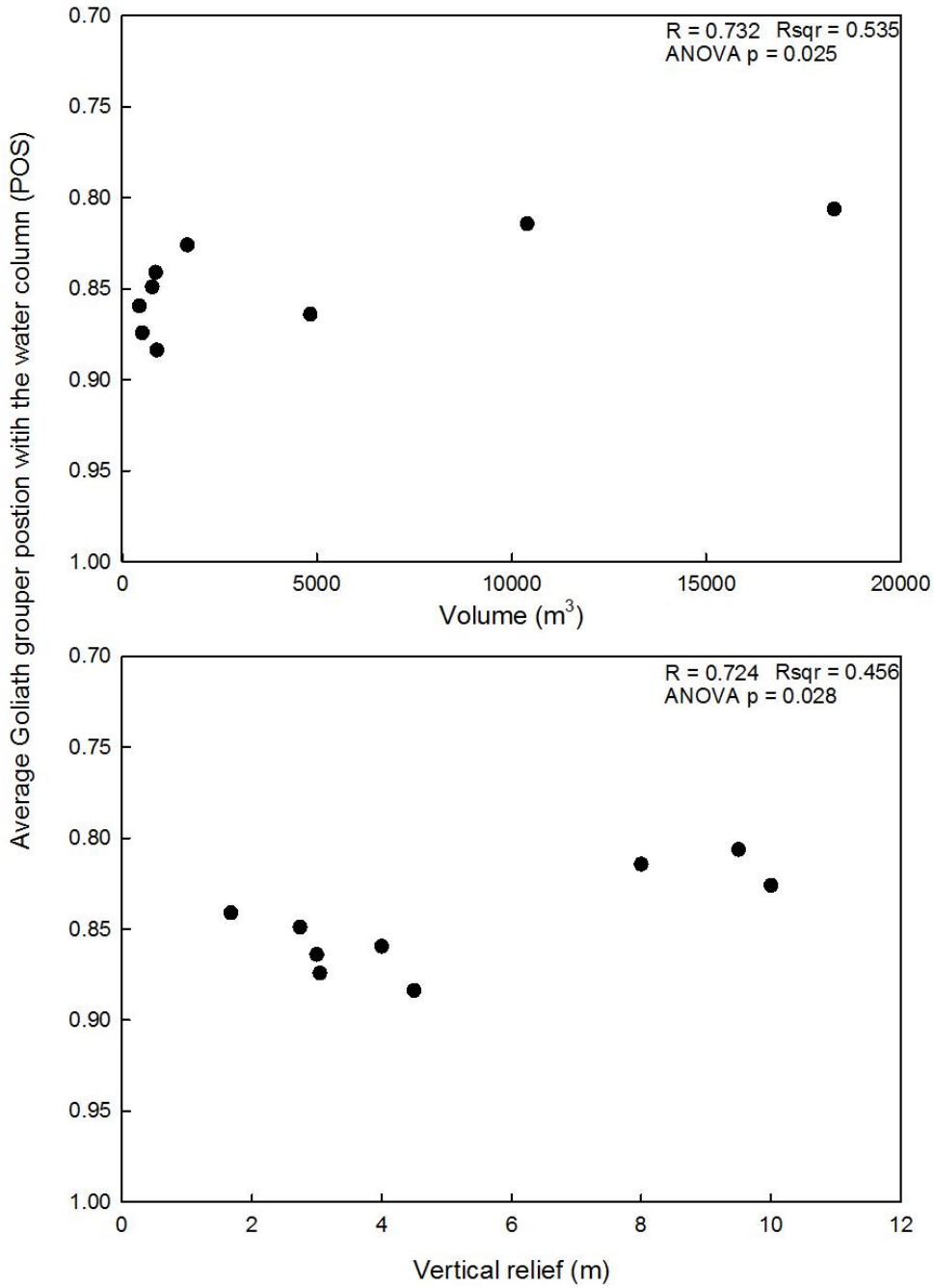

Fig. 13. Goliath grouper *Epinephelus itajara* position within the water column, as related to the volume and vertical relief of the site. Position is standardized across sites by dividing fish depth by the maximum depth of the site, such that 1.0 corresponds to the bottom and 0.0 corresponds to the surface.

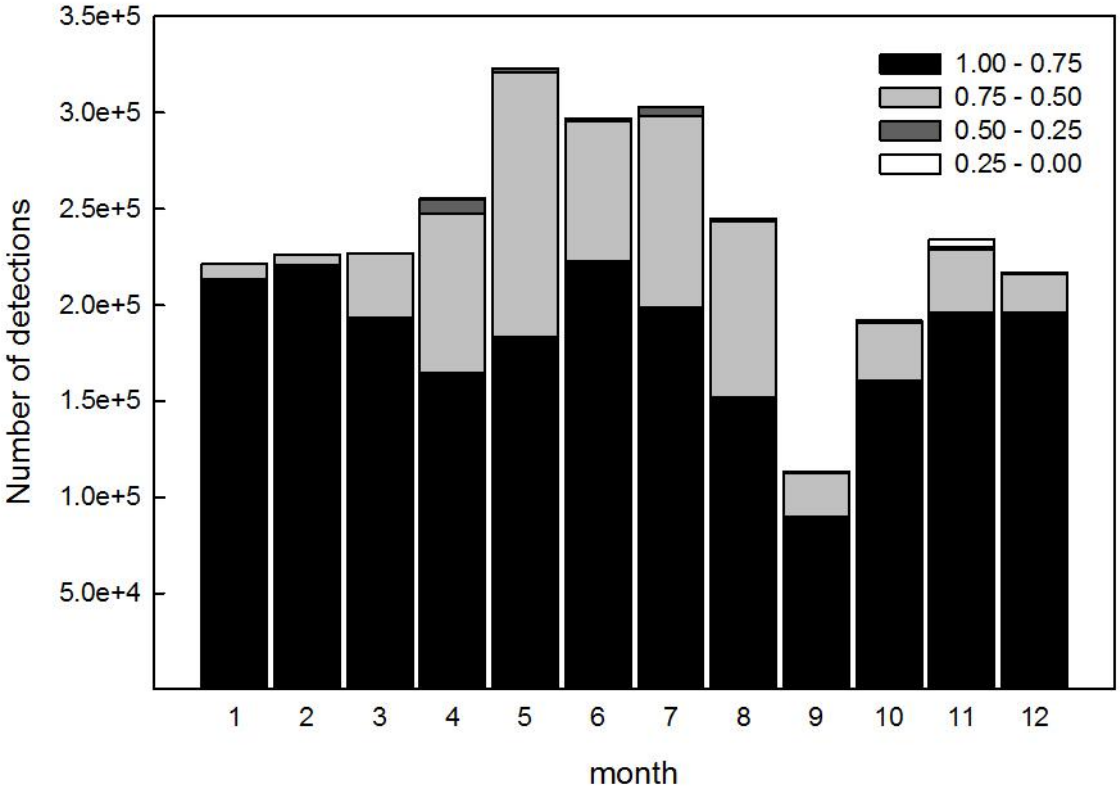

Fig. 14. The number of detections of Goliath grouper *Epinephelus itajara* during each month within each quarter of the water column. Position is standardized by dividing fish depth by the maximum depth of the site, such that 1.0 corresponds to the bottom and 0.0 corresponds to the surface (i.e., 1.00 – 0.75 is the bottom quarter of the water column.)

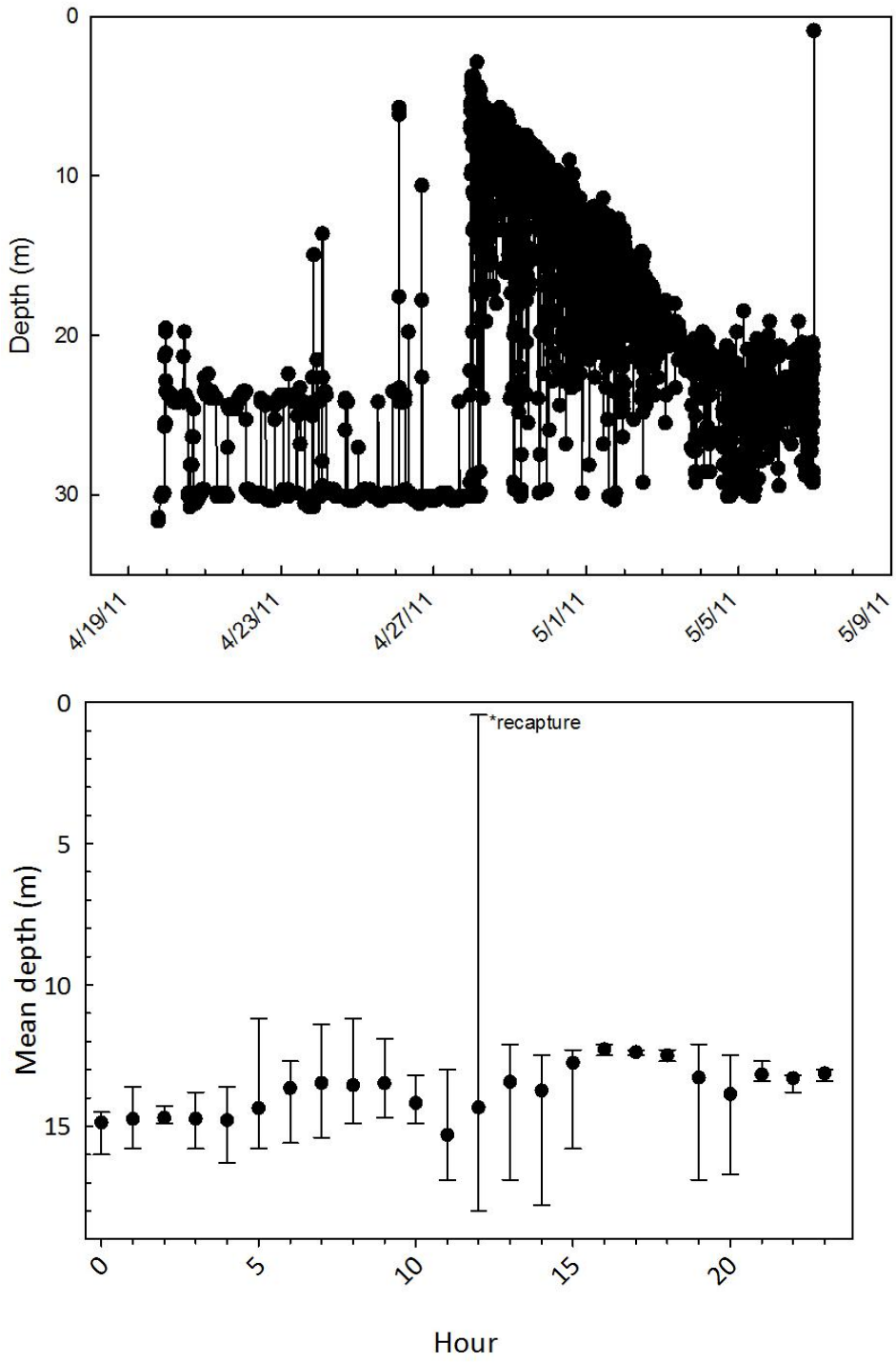

Fig. 15. Example of potential catch and release mortality, illegal harvest or tag removal (top graph). Raw depth position data through time is indicated by symbols, with the last detection at 0 m. Example of catch and release event of Goliath grouper, *Epinephelus itajara*, recaptured by the authors (bottom graph). Mean hourly position before and after catch and release is indicated by symbols; minimum and maximum depth per hour are identified by error bars.

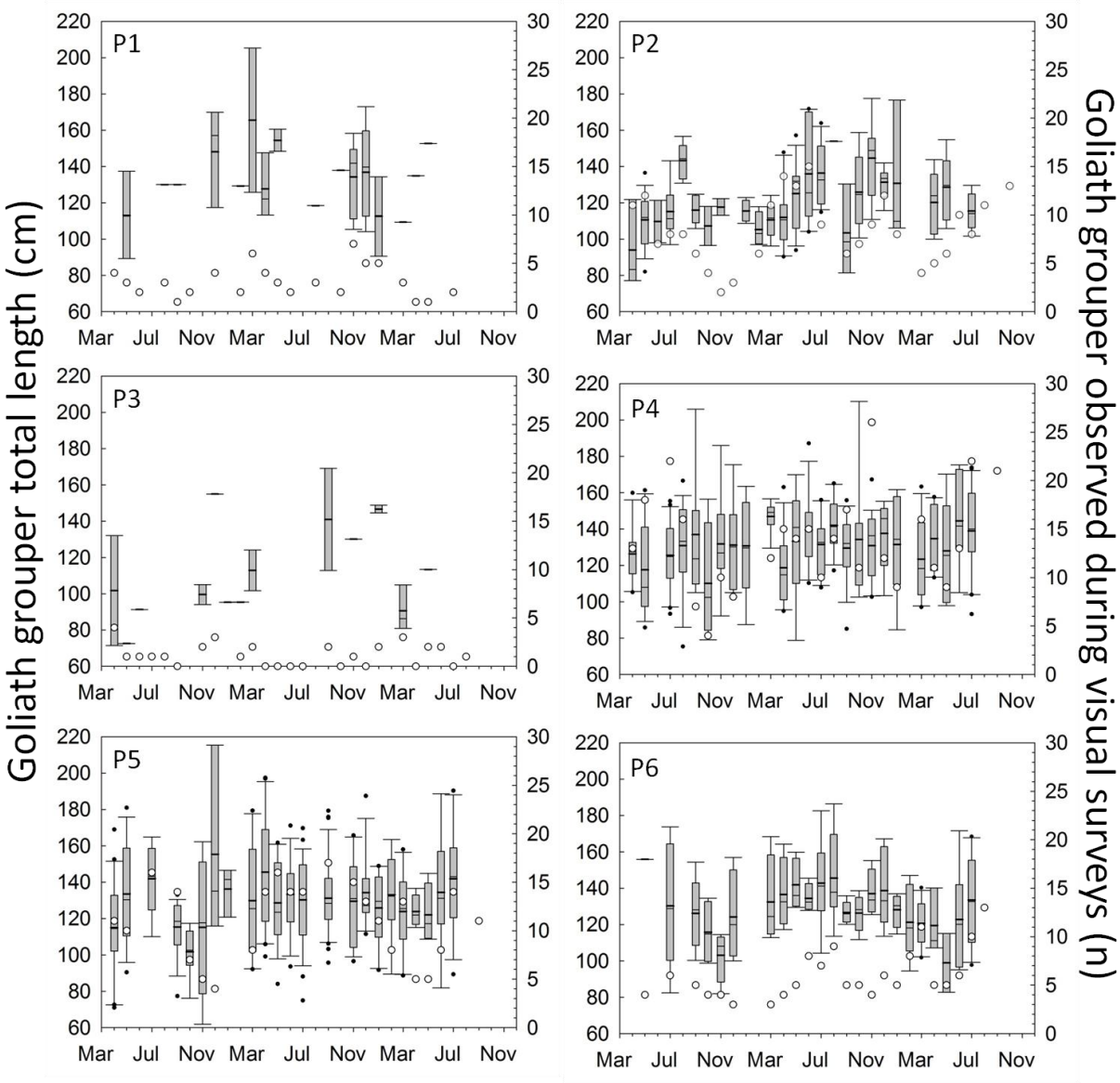

Fig. 16. The size distribution (box plots) and number (○) of Goliath grouper, *Epinephelus itajara*, observed during visual surveys at each of the six main study sites during the study period (April 2011 – November 2013). Box plots indicate the 25 – 75 quartiles, whiskers indicate 95% confidence intervals, and observations falling outside of the 95% confidence intervals are indicated by (●). The mean and median are indicated by the bold and thin horizontal lines, respectively.