Behavior, Habitat, and Abundance of the Goliath Grouper, *Epinephelus itajara*, in the Central Eastern Gulf of Mexico

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Abstract

A cooperative team of scientific, recreational and commercial SCUBA divers was organized to collect data regarding goliath grouper habitat associations, abundance, size distribution and site fidelity in the central eastern Gulf of Mexico. Surveyed sites included both artificial reefs and natural habitat distributed across a range of depths from 7 to 48 meters. Goliath grouper were observed during all months of the year and were present during 74% of all surveys (280/378). Presence and abundance were significantly related to habitat type and depth, with highest presence and abundance recorded over deep, artificial reefs. The maximum number of goliath grouper observed during a single survey ranged from 0 to 24. The mean number observed per site over artificial reefs was 4.53 versus 0.45 over natural habitat. The number of fish observed over artificial habitats tended to increase with site depth and site size. Individual sites tended to hold approximately the same number of individuals throughout the year. There was not a significant seasonal effect on abundance or presence; however, the highest numbers of individuals were observed during the summer months. Goliath grouper were measured via underwater videography, and ranged in size from 40 – 205 cm total length (TL). The majority of individuals observed were between 100 -150 cm TL; however, multiple small (< 100 cm) and large (> 150 cm) individuals were also observed throughout the depth range surveyed. A total of 172 goliath grouper were fitted with external identification tags, and 27 individuals were resighted or recaptured throughout the study period. Time at large ranged 1 – 713 days. The majority of resighted individuals were observed at the same site as their initial tagging, although fish were documented to move as far as 203 km. Growth parameters were estimated for fish collected opportunistically during mortality events and did not differ from those previously calculated for goliath grouper; however, due to the restricted size and age range (11 – 190 cm TL and 1 – 16 years, respectively) and small sample size (n=60) these data should be interpreted with caution. The information collected during the course of this project should provide insight regarding the ecology of goliath grouper within the study area and can potentially assist with future management efforts involving this protected species.

Executive Summary

The goliath grouper Cooperative Research Project was initiated as a joint research effort between divers and scientists in order to explore goliath grouper distribution and abundance along the central west coast of Florida. The main objectives of this project were to quantify goliath grouper presence at specific sites over time. Specifically, this research aimed to address how goliath grouper presence, abundance and size distribution are related to habitat, depth and season. As public pressure to reopen the fishery increases, this information is important for proper assessment of the recovery of the species.

Methods typically used to assess the status of a stock are not available for goliath grouper (i.e., landings data) (Porch et al., 2006). Research efforts must therefore involve a directed, fishery independent approach. Since the fishery closure in 1990, the majority of research efforts have been concentrated along the southwest coast of Florida (from Charlotte Harbor to the Florida Keys) and much of this has been within inshore juvenile habitat (Eklund and Schull 2001; Frias-Torres, 2006; Koenig et al., 2007) (but see Koenig and Coleman, 2009). It was the goal of this research to address the central west coast of Florida (Tarpon Springs to Tampa Bay), and specifically, to examine offshore goliath grouper abundance and size distribution at designated sites over time. This area has historically been a center of abundance for this species and is thus an ideal location to gather information regarding the recovery of the stock.

Dive surveys were performed over a variety of habitats and a range of depths (7 – 48 m) during all months of the year between October 2007 and May 2010. Survey sites were allocated to include both artificial reefs and natural bottom habitat, and were further classified as “shallow” (≤ 20 m) or “deep” (> 20 m). Each dive survey involved an intensive systematic search of the entire site (including all cracks and crevices as well as the surrounding perimeter). Observed goliath grouper were filmed and sizes were estimated using an underwater video camera fitted with equidistant laser pointers (calibrated 10 – 20 cm apart). Still images were removed from video footage and total lengths were estimated in the laboratory using image analysis software. Sizes were calculated only for those fish that were filmed perpendicular to the optical axis of the camera. After the initial survey to determine presence and abundance, as many goliath grouper as possible were fitted with external identification tags in an effort to obtain information regarding site fidelity and movement patterns.

Goliath grouper presence and abundance were significantly higher over artificial habitat during all months of the year. The highest number of goliath grouper observed during a single survey over natural habitat was 3 (mean = 0.43), while up to 24 individuals were observed over artificial habitat (mean = 4.53). Goliath grouper were most common and occurred in highest numbers over deep (> 20 m) artificial reefs (typically shipwrecks). Artificial reef size (specifically, relief and volume) also increased in deep water, confounding the relationship between abundance and depth. Highest numbers of fish were observed during the summer months, although there was not a significant seasonal effect on presence or abundance, and most sites surveyed repeatedly tended to have similar numbers of goliath grouper present throughout the year. Observed fish ranged in size from 40 – 205 cm TL, with the majority of observed fish estimated between 100 – 150 cm TL. Total length did not exhibit a significant relationship to habitat

type or depth, with small (<`100 cm) and large (> 150 cm) fish occurring over both artificial and natural reefs and throughout the depth range sampled.

A total of 172 goliath grouper were fitted with external identification tags, and 27 fish (16%) were resighted or recaptured throughout the study period. Time at large ranged 1 – 713 days. Eight individuals were resighted multiple times throughout the study period. The majority of resighted individuals were observed at the site of their initial tagging, supporting previous accounts of high site fidelity ((Eklund and Schull, 2001; NMFS, 2006; Koenig and Coleman, 2009). However, fish were documented to move distances up to 203 km from original tagging sites, providing further evidence for individual variability between movements.

Life history data were collected opportunistically throughout the study period during natural (i.e., cold kills) or anthropogenic (bridge demolitions) mortality events. Fish were measured and otoliths (n=60) and gonads (n=23) were collected when possible. Sampled goliath grouper ranged 112 – 1900 mm TL and 1-16 years. Sex was confirmed through gonad histology. Males ranged 790 -1750 mm TL and 4 – 10 years, and females ranged 644 – 1650 mm TL and 2 – 11 years. Conclusive evidence for protogyny was not detected. Growth parameters calculated did not differ significantly from previously published data for the species (Bullock et al., 1992); however, these data should be interpreted carefully due to the low number of sampled fish.

This information provides further insight regarding the ecology of goliath grouper and can be applied to future management efforts involving this protected species. Data collected can be used to model responses of goliath grouper populations to potential changes in the effects of new regulation. In light of the recent de-listing of the goliath grouper (NMFS 2006), this information is essential for documenting the status and trends of goliath grouper not only along the west coast of Florida but also elsewhere in the U.S.

Purpose

Description of the Problem

Goliath grouper (Serranidae: *Epinephelus itajara*) occur in tropical and subtropical waters of the U.S., including the Gulf of Mexico and Caribbean Sea. This species of grouper can grow to over 2.5 meters in length and 400 kg (FAO, 2005), and specimens have been aged up to 37 years (Bullock et al., 1992). Fishing for this species was banned in 1990 in federal waters (GMFMC, 1990) as well as all Florida state waters after a noted dramatic decline in population numbers. The protection of this species was based on minimal data, but that data was convincing because this fish is slow-growing, late to mature, and aggregates to spawn - all factors that increase vulnerability to overfishing (Bullock and Smith, 1991; Bullock et al., 1992; Eklund and Schull, 2001). At least one quarter of all goliath grouper spawning aggregations were believed to be extirpated in 2000 (Musick et al., 2000). In 1994, *E. itajara* was listed as critically endangered on the IUCN World Conservation Union's Red List of Threatened Species (www.iucnredlist.org). The species has since been protected in Brazil (2002), Puerto Rico (2004) and the US Virgin Islands (2004; NMFS, 2006). However, fisheries remain for goliath grouper in other parts of the Caribbean (i.e. Honduras and Belize), and the status of the species throughout its entire geographic range remains unclear. After nearly 16 years of protection in the United States, a status report showed a significant increase in goliath grouper abundance throughout U.S. waters, and NOAA removed goliath grouper from the species of concern list in February 2006 (NMFS 2006). Goliath grouper remain protected from harvest in U.S. waters at this time due to uncertainty regarding the population within other regions, as well as concerns regarding the species' vulnerability to overfishing. However, increasing reports of goliath grouper sightings have led to a growing public perception that the species is recovered. Spearfishers describe increasing interactions with goliath grouper, and anglers report higher incidences of goliath grouper attacks on hooked fish. Lobster fishers also claim that rising goliath grouper numbers are negatively impacting lobster harvests. These interactions, combined with the delisting of the species, have spurred public interest to reopen the fishery.

The recovery and present status of goliath grouper within U.S. waters should be thoroughly evaluated before altering regulatory guidelines. Traditional fishery-dependent data are not available (i.e., landings data); thus estimates of population demographics and recovery are dependent upon directed, fishery independent research efforts. The majority of research involving goliath grouper began after the stock was already overfished, resulting in the absence of an existing "baseline" with which to compare current population parameters. Knowledge of fish movement, behavior and habitat associations has been used to exploit many species of fish; thus, this knowledge is critical for the creation of regulatory guidelines regarding conservation (Walters and Martell, 2004). In the absence of catch or landings data, replication of visual surveys over a range of depths and habitat types over time can provide an index of abundance within the study area (i.e., Porch and Eklund 2004; Porch et al., 2006). Additionally, quantification of the size distribution can provide evidence for the size structure of the stock and will also assist with future stock assessment.

It was the goal of this project to provide information regarding abundance, size distribution, habitat association and movement patterns of goliath grouper at specific sites along the west coast of Florida. The west coast of Florida has historically been the center of abundance for goliath grouper, making it an ideal location to explore the recovery of the species. Before the moratorium, the majority of commercially harvested fish were landed along Florida's Gulf coast (Bullock et al., 1992). Extensive research on this species has been conducted in southwest Florida (e.g. Eklund and Schull, 2001; Frias-Torres, S., 2006; Koenig et al., 2007), but a paucity of published information is available pertaining to the status of goliath grouper in the current study area (but see Koenig and Coleman, 2009). This project addressed a unique region with a need for quantitative information regarding goliath grouper distribution and abundance.

Project Objectives

This project involved recreational and commercial fishermen and divers in the collection of fundamental fisheries information. A cooperative team of scientific, recreational, and commercial SCUBA divers was organized to observe and tag goliath grouper in coastal and offshore waters of Florida's central west coast. The resulting information should expand the understanding of goliath grouper ecology within the study area, which is necessary to support responsible management of this living marine resource.

The primary goals of this project were to describe habitat associations, size distribution, abundance and movement patterns of goliath grouper in the eastern Gulf of Mexico, with the added potential to collect life history data at certain points throughout the duration of the project. The objectives of this research were to utilize *in situ*, underwater observations to address the following:

- relative abundances of goliath grouper based on habitat type, depth and season in the eastern Gulf of Mexico;
- site fidelity for goliath grouper;
- size structure, spawning and non-spawning behaviors, and spatial and temporal variations in habitat associations;

Additionally, opportunistic collection of life history samples throughout the course of the study period should allow researchers to:

- synthesize fisheries information and life history parameters for Florida's goliath grouper population with other regions in the western Atlantic, Caribbean Sea, and Gulf of Mexico.

Specifically, we anticipate this project will assist with answering the following questions:

- What are the general characteristics of the goliath grouper population in the central eastern Gulf of Mexico, and is their abundance or distribution characterized by habitat or depth? Do some local densities of goliath grouper increase at certain times of the year (i.e., during spawning?) This was assessed by quantifying fish distributions, associated habitat variables including depth and habitat type, and by repeatedly visiting the same sites throughout all seasons of the year.

- Do large aggregations of goliath grouper consistently occur at the same locations (i.e. wrecks that always hold at least 5-10 fish)? Do the same fish remain at a location for extended periods and does this change with fish size, depth, habitat type or season?
- At what size do goliath grouper begin recruiting to offshore habitat in the central eastern Gulf of Mexico and how does this compare to existing data available for other areas?
- How stable are goliath grouper life history parameters in the eastern Gulf of Mexico (i.e., are growth rate estimates as measured in this study statistically different than previously published estimates [Bullock et al., 1992])?

Approach

Description of work

***In situ* observations: Habitat association, abundance and size distribution of goliath grouper**

Cooperative research dives paired a researcher (ABC) with an AAUS-certified recreational or commercial diver from the St. Petersburg Underwater Club (SPUC). As the CRP industry partner, SPUC members played a critical role in the development of dive locations designated for this study. Dive surveys were conducted throughout all months of the year during daylight hours. Adult goliath grouper inhabit both artificial and natural habitat (Heemstra and Randall, 1993) and generally occur in depths less than 50 m (Bullock et al., 1992), so dive sites were distributed across a range of depths (to 50 m) to include both artificial and natural habitat (Fig. 1). Artificial habitat was defined as any man-made structure (primarily shipwrecks, but also included any other man-made artificial reefs). Natural habitat included limestone ledges, reef pinnacles, and rock piles common to the study area.

Sites were classified by depth as shallow (≤ 20 m) or deep (20 - 50 m). Sites designated for seasonal sampling (n=21) were surveyed at least once per season (although many sites were visited more often, depending on weather conditions). Seasons were defined as winter (January – March), spring (April - June), summer (July – September), and fall (October – December). To provide further information, additional locations (n=63) surrounding the designated 21 sites were surveyed opportunistically throughout the study period. Maximum relief was recorded for all sites. Additional features (length and width) were also recorded for all sites visited more than once.

Only sites that could be completely surveyed (from one end to the other) during a single dive were considered for this study. Survey effort (time on bottom) was positively related to the total area of the site; however, research protocol mandated a minimum bottom time of at least 15 minutes. Water-quality parameters (surface and bottom temperature, dissolved oxygen, salinity) were recorded prior to each survey using a YSI multi-probe meter (Yellow Springs Instruments, Model 85), and horizontal visibility was qualitatively assessed during each dive by the surveyor. Dives performed in visibilities less than 3 m and surveys lasting less than 15 minutes were excluded from abundance analyses.

Visual census and underwater video were used to quantify the abundance and size distribution of goliath grouper during each survey. Goliath grouper presence and abundance were assessed during a thorough visual inspection of the entire site upon arrival. At the beginning of each dive, the researcher swam methodically in a single direction from one end of the site to the other in order to survey the entire structure. All crevices, holes and underhangs were inspected (Sluka et al., 1998; Lindberg et al., 2006), and a search of the surrounding perimeter was performed (while maintaining visual contact with the site). Goliath grouper were considered present if at least one fish was observed during the dive survey. To minimize pseudo replication, abundance values are minimum estimates defined as the number of goliath grouper encountered during a systematic one-way survey of the area. All attempts were made to identify characteristic marks of individual fish to reduce the chance of double-counting. Observed fish were documented using underwater video. During filming, a custom made laser apparatus (fitted to the top of the video camera housing) projected equidistant points onto the subject. To obtain size estimates, still frames of recorded fish were cut from the underwater video and imported into image analysis software (Image Pro Plus). Total length (TL) was estimated to the nearest cm only for fish that were filmed perpendicular to the optical axis of the camera. In cases when fish would not orient properly, or the researcher could not get close enough to project the lasers onto the fish body, total lengths were estimated to the nearest 15 cm by the observer and further categorized as small (< 1 m TL), medium (1 – 1.5 m TL) or large (>1.5 m). Whole body weight was estimated using the length–weight equations established in Bullock et al. (1992). Additional observation efforts were made during suspected spawning months (June – October; Bullock et al., 1992) to better describe spawning behaviors and aggregations within the study area.

After the initial survey to determine goliath grouper abundance and size distribution, as many fish as possible were fitted with conventional external identification tags. Identification tags consisted of a large nylon dart fish tag (Floy BFIM96 Billfish tag) modified with an oversized plastic ID tag (6.5 x 3 cm) with enlarged text (2 cm font height) to increase visibility and resighting potential (Fig. 2). A tagging hotline telephone number was prominently displayed to encourage angler reports of fish captured on hook and line. Prior to deployment, tags were sprayed with clear anti-foul paint (Aquagard Alumi-Koat, Flexdel Corp., NJ) to minimize the effects of biofouling. Tags were attached *in situ* using a modified speargun to shoot the tag dart into the dorsal musculature directly beneath the dorsal fin. Goliath grouper less than 100 cm TL were not tagged. During all surveys, goliath grouper were examined for evidence of previous tagging as well as other unique identifying external characteristics (i.e., torn fins or distinctive markings). The date, time, location, and tag condition were recorded for all resighted or recaptured fish.

Generalized linear mixed models (Proc GLIMMIX, SAS) were used to identify potential relationships between goliath grouper presence and abundance and site characteristics (depth range, habitat type [artificial or natural], or season). Seasonal differences in presence and abundance were also investigated between habitat and depth range for the overall sample, as well as for individual sites.

Opportunistic Collection of Life History Data: Age, growth, and reproduction

FWRI staff opportunistically collected biological samples from all incidental goliath grouper mortalities that were reported to FWC (i.e., through bridge demolitions, cold weather, harmful algal blooms or natural mortality). At a minimum, measurements (TL, SL, and weight), location (latitude/longitude) and a DNA sample (fin clip) were collected for each fish. Otoliths (sagittae), gonads, stomach contents, and tissue samples for parasite, toxin and mercury analyses were collected when possible, depending upon the decomposition level of the specimen.

Otoliths were used to assign ages to fish following Bullock et al. (1992). Otoliths were cleaned and sectioned along the transverse plane using a low-speed saw. Sections were mounted permanently to coded glass slides, and read using reflected light under a binocular scope. The total number of annuli was counted to determine a final age for each specimen (number of annuli equals age; Bullock et al. 1992). Growth was modeled using the von Bertalanffy growth equation:

$$TL = L_{\infty}(1-e^{(-K[t-to])})$$

where L_{∞}= asymptotic fork length, K is the von Bertalanffy coefficient and t_0 is the predicted age at which fish length is equal to zero. Modeled growth was compared to that of Bullock et al. (1992).

Gonads were collected whenever decomposition level was minimal enough to allow for sampling. Gonads were weighed and a thin cross section from the middle of the gonad was removed and fixed in 10% buffered formalin for at least 48 hours. Gonad samples were then rinsed and stored in 70% ethanol. Samples were then embedded in glycol methacrylate, sectioned along the transverse plane and stained in periodic acid Schiff's haematoxylin and counterstained with metanil yellow (Quintero-Hunter et al., 1991). Slides were read at least twice by a single reader at 100-200x magnification, and sex was designated as male or female. Females were assessed by noting the most advanced oocyte stage. Males were assessed by noting the stages of spermatogenesis.

Cooperative Planning and Communication

Throughout the study, communications were kept open between FWC/FWRI and SPUC in a variety of formats. Dive planning and research updates occurred through an informal communication network (telephone and email). Assessment meetings were held over the course of the project to review accomplishments and discuss necessary adjustments. Quarterly progress reports were submitted to the SPUC liaison, Rich Taylor, prior to submission to NOAA, for SPUC review. Additionally, draft and final versions of reports produced from this research were made available to participating SPUC members for review and comment.

Project Management

Participation by Recreational and Commercial Fishermen

The St. Petersburg Underwater Club (SPUC) served as the cooperative research partner during the course of this work. SPUC was founded in 1952 and is considered the oldest sport diving club in the United States. This spearfishing club has over 200 members (active and inactive), and is affiliated with Sportsmen Protecting Ocean Resources Together (SPORT), which links divers along Florida's entire west coast. The composition of membership in SPUC and SPORT includes predominantly recreational divers, but a few commercial divers as well. Fifteen SPUC members attained training that met the requirements of an AAUS (American Academy of Underwater Sciences) certified diver. This mandated training allowed them to officially serve as dive partners for state researchers, and they reliably served as dive buddies and fish taggers during visual surveys. Together with other SPUC members, they consistently shared site location information and provided reliable offshore research support throughout the duration of this project. SPUC members have a wealth of historical knowledge regarding bottom habitat and fish distribution within the study area, and provided all boat transportation to and from dive sites.

Captain Rich Taylor was the SPUC liaison and spokesman for the length of this project. Taylor, a past-president of SPUC, has also served as a panel member on two separate goliath grouper SEDAR panels (January, 2004; Tampa, FL; April 2010; St. Petersburg FL) and is well aware of the research needs relevant to this species. He was a significant participant in our previous hogfish CRP (NA05NMF4540040), continued to actively participate in the research objectives of the current goliath CRP, and played a critical role in facilitating communications between researchers and participating SPUC divers.

Participation by Research Scientists

The Fish and Wildlife Research Institute was awarded the CRP grant (NA07NMF4540085) that funded the work described herein. All technical aspects of this study were managed by Angela B. Collins, who conducted the necessary field and laboratory work and kept open the communications between FWC and participating divers and fishermen. Collins was responsible for dive operations, fish sampling, laboratory processing of samples, video and image analysis, data analysis and interpretation, and report preparation. Dr. Luiz R. Barbieri oversaw and performed quality control of research progress, and assisted with interpretation and summarization of final results. Ms. Linda Torres managed the financial and administrative requirements of this project. Collins, Barbieri and Torres were based at the FWRI headquarters in St. Petersburg, Florida. Dr. Todd Kellison served as the NOAA/NMFS technical advisor and provided guidance throughout the duration of this research.

Findings

Accomplishments and Findings

***In situ* observations: Habitat association, abundance and size distribution of goliath grouper**

Cooperative research dives (n=378) took place during 121 offshore trips between October 11, 2007 and May 8, 2010. Over the course of the study, 45 natural sites (survey n = 110) and 39 artificial sites (survey n = 268) were surveyed for goliath grouper. Sites ranged in depth from 7 – 48 m and surveys were performed during all months of the year (Fig. 3). Bottom temperature ranged 14.1 – 31.7 °C. The frequency of surveys for each site was dependent upon weather conditions and the presence of other boaters, and ranged 1 – 29 visits per site (Fig. 4). Sites established for seasonal monitoring (n=21) were visited at least once per season.

Total survey effort (time on bottom) was 13,401 minutes (223 hours). The average survey time per site was 35 minutes (range: 8 – 125 min). If bottom time did not exceed 15 minutes (n = 13 dives; 3%), or visibility was < 5 m (n = 29 dives; 7.6%) only presence/absence data were considered (i.e., abundance and size distribution data were omitted from the analyses for these dives).

Presence

Goliath grouper were present during 280/378 dive surveys (74%). Goliath presence was significantly related to habitat (p<0.0001, F=84.45), and fish were much more likely to be encountered over artificial (242/268 surveys; 37/39 sites) than natural habitat (38/110 surveys; 18/45 sites) (Fig. 5). Presence was also significantly related to depth (p=0.0143, F=6.05), with fish observed more often at “deep” sites (>20 m; 145/170 surveys; 30/41 sites) than “shallow” sites (≤ 20 m; 135/208 surveys, 25/43 sites). Overall, there was not a significant relationship between goliath grouper presence and season (p=0.0689, F=2.39), nor were significant interaction effects detected between habitat and depth (p=0.3063, F=1.05), habitat and season (p=0.1674, F= 1.70), or depth and season (p=0.1042, F=1.77).

Abundance

The number of goliath grouper observed during a single survey ranged 0 – 24 (Fig. 6). As with presence, significantly higher numbers of goliath grouper were observed over artificial than natural habitat (p< 0.0001, F = 160.01), and this pattern was evident throughout all months of the year (Fig. 7). Deep (>20 m) sites had higher numbers of goliath grouper than shallow (≤20 m) sites (p<0.0001, F=18.47). Highest numbers of goliath grouper were observed over artificial habitat in deep water (>20 m) during all seasons (Fig. 8). For artificial reefs, there was a significant positive relationship between site size and site depth (p<0.0001). The largest and highest relief sites occurred in deeper water, indicating that the increased abundance of goliath grouper at deep sites is likely related to site size. Additionally, individual sites tended to hold similar numbers of goliath grouper throughout the study period (Fig. 9), suggesting that individual site characteristics affect the number of goliath grouper present. Highest numbers of goliath grouper were observed over artificial habitat during the summer months (Fig. 10; Fig. 11). However, there was not a significant statistical relationship between abundance and season (p=0.4240), nor were there significant interaction effects between habitat and season (0.9640) or depth and season (0.5417).

Goliath grouper spawning season in Florida has been identified as June – October, peaking July – September (Bullock et al., 1992; Mann et al., 2009). Highest numbers of goliath grouper corresponded with this time frame over both summers that research was conducted. No actual spawning was observed during this study; however, there were distinct behaviors that occurred at two different sites during summer months that have previously been associated with spawning. Specifically, some goliath grouper displayed blanched heads and darkened bodies (Colin 1990). Alternately, some fish displayed completely darkened bodies, while others displayed completely blanched coloration. This has also been noted at a spawning aggregation on the east coast of Florida (Phelan 2009). These color patterns were particularly obvious in June, July and August, when fish also were observed "stacking" in the water column at the perimeter of the shipwreck. This "stacking" behavior consisted of fish (at some points up to 16 individuals) tightly grouped approximately 10 – 25 feet off the bottom, typically oriented in a similar direction, at the edge of the artificial reef (Fig. 12).

Size distribution

Underwater videography and image analysis yielded measurements for 63% of the goliath grouper that were observed. The remaining observed fish lengths were unable to be verified through image analysis due to low light conditions, environmental interference with the laser beams (i.e., baitfish or particulate matter) or failure to achieve a filming angle that placed the fish perpendicular to the optical axis of the camera. In these cases, total lengths were estimated to the nearest 15 cm by the observer and classified as small (< 1 m TL), medium (1 – 1.5 m TL) or large (>1.5 m).

The majority of individuals observed were between 100 – 150 cm TL (Fig. 13). Fish lengths verified through image analysis ranged in size from 40 to 205 cm TL. There was not a significant relationship between fish size and site depth or habitat type. Fish as small as 67 cm TL were verified from sites as deep as 36 m (Fig. 14). The size of fish observed in shallow (≤ 20 m) water ranged 40 – 205 cm TL, while fish measured in deep (> 20 m) water ranged 61 – 201 cm TL. Both large and small individuals were observed throughout the study area over all depth ranges. No relationship between fish size and time of year was detected, with similar size ranges observed over both depth strata throughout the study (Fig. 15).

Site fidelity and movement

A total of 172 goliath grouper were fitted with external identification tags between November 9, 2007 and May 8, 2010. Resightings have been verified for 27/172 (16%) individuals (Table 1). Two of these individuals (YS and HK) were not tagged with conventional tags but did have identifying features that allowed for easy visual recognition. Additional tagged fish (n=17) were resighted but could not be positively identified due to inability to read the tag (biofouling, low light levels or fish distance from observer). Time at large ranged 1 – 713 days, and eight individuals were resighted multiple times (2 – 5 resightings per fish). Recaptures were reported as far as 203 km away from the initial tagging site, but most resightings or recaptures occurred in the same location as the initial tagging event. The majority of fish were tagged at artificial habitats (166/172 tagged fish), and all resightings occurred at artificial habitat. Six individuals were verified at locations other than their initial tagging site, five of them providing evidence for some movement between artificial reefs within the study area and one showing movement out of the study area (Fig. 16).

Opportunistic Collection of Life History Data: Age, growth, and reproduction

Since 2006, 105 fish have been encountered and opportunistically sampled for life history information (Table 2). Most of these samples were collected on the west coast of Florida (n=95), and the majority of these were collected from shallow water during the cold weather event in January 2010 (n=67). The remaining fish were collected sporadically along the east coast (Indian River Lagoon) and in the Dry Tortugas (Fig. 17). Otoliths were collected and corresponding ages determined from 60 of these samples. The remaining fish were sampled only for lengths and DNA because they were either too decomposed for additional tissue collection (n=38) or were sampled during a catch and release event (n=7). Sizes of opportunistically sampled goliath grouper ranged 112 – 1900 mm TL and 1-16 years (Fig. 18). The von Bertalanffy growth parameters (L_∞ = 2312.9 ± 450.6, k=0.1107± -0.0394, t_0=-0.1790 ± 0.4468; ± standard deviation within 95% confidence limits) calculated during this study for pooled length and age data are similar to those calculated by Bullock et al. (1992) (Fig. 18). However, these data should be interpreted with caution due to the low number of fish collected in the current study. The data collected here do not allow for confirmation that growth rates have not changed since the work by Bullock et al. (1992) (for fish collected in the 1980s), and more data are needed before this question can be addressed. Sex was confirmed through gonad histology for 23 fish. Confirmed females (n=14) ranged 644-1650 mm TL and 2-11 years. Males (n=9) ranged 790 – 1750 mm TL and 4 – 10 years. Three of the males (ages 4 – 5 years) exhibited primary growth oocytes scattered throughout the gonad (Fig. 19). This character is not a reliable feature for discounting gonochorism (Shapiro, 1987; Bullock et al., 1992); however, together with the presence of a central lumen and the lamellar structure of the testicular tissue, it does provide further support for protogyny (Shapiro, 1987; H. Grier, pers. comm.).

Conclusions

Goliath grouper are opportunistic ambush predators and prefer complex habitat with adequate cover (Sadovy and Eklund, 1999), and their association with artificial reefs has been well established (Eklund and Schull, 2001; Garcia-Tellez et al., 2002; Gerhardinger et al., 2006; NMFS, 2006; Koenig and Coleman, 2009). Thus, the correlation between artificial habitat and goliath grouper presence and abundance detected during the current study was not surprising. The majority of natural bottom habitat surveyed within the study area consisted mostly of moderate relief ledges (limestone outcroppings; mean relief = 1 m), which may not provide adequate cover to accommodate large numbers of goliath groper. In contrast, most of the artificial reefs surveyed included shipwrecks, which have high relief and abundant structure that can provide shelter and (apparently) sufficient resources for multiple goliath grouper.

Presence and abundance did not show a significant statistical relationship to season, although there was a noted absence of goliath grouper from shallow, northern sites during the coldest months of the year. The highest numbers of goliath were observed over large artificial reefs (shipwrecks) during the summer months (July – September), and it is suspected that this is related to spawning behavior. To date, all documented spawning sites have been associated with high relief structure (Sadovy and Eklund, 1999). Spawning behaviors observed during this study occurred the summer months and included fish stacking in the water column and displaying color patterns associated with reproduction (Colin 1990; Phelan 2009). Actual spawning was not observed during any of the dive surveys; however, all surveys were performed during daylight hours and recent work by Mann et al. (2009) suggests that spawning likely takes place at dusk or after dark.

Goliath grouper were expected to maintain high site fidelity based on observations from other researchers. Eklund and Schull (2001) performed a tagging study on adult goliath grouper and reported resighting individual fish at the same location for up to three years. Similarly, acoustically monitored juveniles remained within small defined areas of the Ten Thousand Islands for many months (Frias-Torres et al., 2007; Koenig et al., 2007). Similar findings were reflected in the current study. The majority of resighted fish were observed at the location of their initial tagging. However, only 16% of tagged fish were resighted. This low number of resighted fish is perplexing because many sites were revisited multiple times throughout the year and fish were expected to remain in the same location for extended periods. Potential explanations include poor tag retention, fish avoiding divers after a tagging event, or movement away from the tagging site. Additional work regarding movement patterns is necessary to better interpret questions regarding site fidelity and goliath grouper behavior.

The majority of observed fish were between 100 – 150 cm TL, suggesting that most fish documented during this study were between 5 – 11 years of age (Bullock et al., 1992). Interestingly, multiple small fish (< 100 cm TL) were also observed throughout the depth range sampled, indicating that some goliath grouper may move out of nursery habitats earlier than previously believed (Bullock et al., 1992; Koenig et al., 2007). The occurrence of large fish (> 150 cm TL) throughout all depths sampled within the study area also demonstrates that permanent movement offshore is not necessarily obligatory with growth. One large (190 cm TL) individual was documented inside Tampa Bay. Additionally, the continued presence of goliath grouper at designated sites throughout the year is intriguing. Goliath grouper aggregate to spawn during the late summer months (Bullock et al., 1992; Mann et al., 2009; D. DeMaria, personal communication) and there is evidence that fish will migrate long distances to reach aggregation sites (Eklund and Schull, 2001; Koenig and Coleman, 2009). During this study, no seasonal effects upon abundance or presence were detected. Most fish observed were of reproductive size (Bullock et al., 1992) but there was no evidence for a seasonal exodus (or conversely, a seasonal immigration from surrounding areas) during the spawning season. Similar numbers of fish were present at seasonally sampled sites throughout the year. Highest numbers were observed during the summer at specific sites (these were the same locations where spawning behaviors were observed) but the continued presence of goliath of reproductive size at surrounding sites should be investigated more thoroughly.

The number of fish collected through opportunistic sampling provided some additional information on goliath grouper age and growth; however, the low number of otoliths (n=60) and gonads (n=23) collected did not allow for a substantial assessment of growth parameters or provide additional evidence for protogyny (and associated sizes at transition). The majority of aged fish were collected from shallow, nearshore water and the oldest individual collected was only 16 years of age. Goliath grouper are known to live to 37 years (Bullock et al., 1992) and it is suspected that fish may live well into their 50s. Additional age and growth data are needed to verify whether or not growth parameters have changed since protective measures were implemented in 1990.

The data collected herein addressed a unique region with a need for quantitative information regarding goliath grouper distribution and abundance. Although continued research is warranted, these data provide additional insight into the biology and ecology of this species. It is hopeful that the resulting information will expand the understanding of goliath grouper ecology within the study area and assist with future management efforts.

Significant problems

No significant problems developed during the course of this study. A nine month extension was requested and granted in order to increase the number of dives that could be performed during the fall and winter months (October – March). Winter weather (increased wind speed and wave height) within the study area often affected researcher ability to safely travel long distances offshore and the granted extension allowed for necessary “make-up” dives.

Description of need for additional work

Continued monitoring of sites established during this study should be performed to allow for prolonged investigation into the recovery of the stock within the study region. This is particularly important considering the severe cold weather event that occurred in January – February of 2010, which is suspected to have had a significant impact on the goliath grouper population within Florida, because significant mortalities of both adults and juveniles were reported throughout the state. Additionally, it is important to consider the possibility of potential impacts from the Deepwater Horizon Oil Spill that took place in April of 2010, at the end of this study.

Research regarding juvenile abundance within inshore habitat is lacking for this area. Further research regarding juvenile abundance and distribution within estuaries along the central west Florida coast is needed to continue to assess the status of the stock, as well as provide additional data regarding critical nursery habitat. A description of the abundance and distribution of goliath grouper within shallow estuarine habitat may be better accomplished through fishing and trapping techniques rather than underwater visual census due to the low visibilities common within these areas.

Finally, a more thorough investigation into movement patterns and spawning behavior of goliath grouper is necessary to better describe the behavior of the species within the study region. Conventional tagging provides important information but allows only for snapshot data regarding fish movement and is dependent upon resighting or recapture reports from divers and anglers. Acoustic telemetry would allow for long-term monitoring and more complete information regarding fine scale movement and activity patters of the species.

Evaluation

Were goals/objectives obtained? Explain.

The goals and objectives set forth in the initial proposal were attained with minimal alteration. The statement of work in the original request for funding was followed and completed, with two exceptions. Monitoring of inshore (inside Tampa Bay) goliath grouper was not possible due to visibilities less than 5 m throughout the study period. Although two sites were initially proposed for visual surveys within Tampa Bay, they were removed from the final analyses. Visual survey protocol required a minimum horizontal visibility of 5 m. This rarely occurs within Tampa Bay and never occurred during a research dive in these locations during the study period. Additionally, specific ages were not estimated for fish observed during underwater surveys. Total lengths were verified to the nearest centimeter for 50% of the goliath grouper that were observed. The remaining fish could not be measured via underwater videography due to improper orientation of the fish to the camera, low visibility or fish distance from the observer, and were thus estimated for total length buy the observer as small (< 100 cm), medium (100 – 150 cm) and large (>150 cm). It was therefore inappropriate to attempt specific age estimation of the population via an age-length key.

The Cooperative Research Program allowed an excellent opportunity to work with an industry partner (The St. Petersburg Underwater Club, SPUC). This allowed for an extremely effective and efficient use of funds, and the number of surveys performed (as well as the number of sites surveyed) actually exceeded the originally proposed target, allowing for enhanced assessment of the study area. SPUC members have an historical and extensive combined knowledge of the habitat and fish distribution within the eastern Gulf of Mexico. This expertise was invaluable throughout the duration of the project.

Were modifications made? Explain.

No significant modifications were made, other than the removal of two inshore Tampa Bay sites from visual census analyses, and the granted 9 month extension to allow for additional dives during the fall and winter months.

Dissemination of Project Results

Results of the completed research should be of interest to others working on reef systems. Goliath grouper are important upper level predators, so this research will be useful not only to those involved with management and regulation of this particular species, but also to researchers with interests in the areas that goliath grouper inhabit. Throughout the duration of this research, eleven presentations about goliath grouper were given to both state and federal management agencies, as well as sport dive clubs, other stakeholder groups, and the general public. These presentations are listed at the end of this section. To date, one manuscript regarding the preliminary results of this research has been published (Collins, 2009; see below). In addition, a brief compilation of the research was submitted as a working paper for the SEDAR23 data workshop for goliath grouper (Collins and Barbieri, 2010; see below). We expect to continue to publish the findings of this work in peer-reviewed, scientific journals (i.e., Fishery Bulletin, U.S.).

Publications:

- Collins, A.B. 2009. A preliminary assessment of the abundance and size distribution of goliath grouper *Epinephelus itajara* within a defined region of the central eastern Gulf of Mexico. 61st Gulf and Caribbean Fisheries Institute Proceedings: 184-190.

- Collins, A.B. and Barbieri, L.R. 2010. Goliath surveys and samples: A summary of recent work by the Fish and Wildlife Research Institute (2006 -2010): A working paper. SEDAR23 Goliath grouper Data Workshop, St. Petersburg, FL. April 27-29, 2010.

The ongoing results of this research have been presented in the form of talks at the following venues:

To state and federal management agencies:

- Collins, A.B. 2008. A preliminary assessment of the abundance and size distribution of goliath grouper *Epinephelus itajara* within a defined region of the central eastern Gulf of Mexico. Gulf and Caribbean Fisheries Institute Annual Meeting, Gosier, Guadeloupe. November 10 -14, 2008.

- Collins, A.B. 2008. A preliminary assessment of the abundance and size distribution of goliath grouper *Epinephelus itajara* within a defined region of the central eastern Gulf of Mexico. Presentation for the FWC Artificial Reef Program, Division of Marine Fisheries Management, Tallahassee, FL December 10, 2008.

- Collins, A.B. 2009. “Goliath grouper in the Gulf: A goliath survey of reefs and wrecks off Florida’s central west coast.” * AFS Florida Chapter meeting, Altoona, FL. February 22, 2009. *This presentation was awarded the Best Professional Paper Award.

- Collins, A.B. 2009. Big Fish Tales: A goliath survey of wrecks and reefs off Florida's central west coast. Gulf and Atlantic States Marine Fisheries Commission Artificial Reefs Subcommittee meeting, St. Pete Beach, FL, October 2009.

- Collins, A.B. 2010. Big Fish Tails: A Goliath survey of reefs and wrecks in the Gulf of Mexico. Florida Artificial Reef Summit, Cocoa Beach, FL. January 2010.

To sport dive clubs, stakeholder groups, and the general public:

- Collins, A.B. 2009. A preliminary assessment of the abundance and size distribution of goliath grouper (*Epinephelus itajara*) within a defined region of the central eastern Gulf of Mexico. Jim's Dive Shop, St. Petersburg, FL. February 5, 2009.

- Collins, A.B. 2009. Getting a Good Look at Goliath grouper in the Gulf. FWRI Marine Quest, St. Petersburg, FL. April 25, 2009.

- Collins, A.B. 2009. Goliath grouper in the Gulf: A goliath survey of reefs and wrecks off Florida's west central coast. Reefseekers Dive Club meeting, Depth Perception Dive Shop, Tampa, FL. May 12, 2009.

- Collins, A.B. 2009. Goliath grouper: The Super-sized seabass of the Bay. Tampa Bay Estuary Program's Estuary Academy, St. Petersburg, FL, October 19, 2009.

- Collins, A.B. 2010. The Hogfish and the Goliath: Tales of Big Fish Tails… Bill Jackson's Scuba Club meeting, St. Petersburg, FL. March 15, 2010.

- Collins, A.B. 2010. The Hogfish and the Goliath: Tales of Big Fish Tails. Sarasota Scuba Club Meeting, Sarasota, FL. April 1, 2010.

Additionally, this research project has been highlighted in the following media formats:

- Florida Sportsman: "Artificial Reefs 2010," by Sam Hudson. June 2010, pp 38 – 43.

- FWRI Focus on Research: Research Spotlight: "Diving into Goliath Grouper Research," by Wendy Quigley. September/October 2010. http://research.myfwc.com/education/view_article.asp?id=35136.

- St. Petersburg Times: "Get to Know Goliath," by Terry Tomalin. August 7, 2009, pp 4L – 5L.

Acknowledgements

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Tables

Table 1. Tag/recapture data for goliath grouper that have been re-sighted since their initial tagging date. Days at large indicates number of days between sightings (* = caught by angler via hook and line). Distance moved corresponds to straight line distance between site of tagging and location of resighting. Individual IDs correspond to their tag ID; individuals HK and YS were not tagged but had distinctive features that allowed for easy recognition.

Individual	Tag date	Resight date	Days at large	Distance moved (km)
1	11/9/2007	11/29/2007	20	0
11*	12/1/2007	6/22/2008*	204	203
18	12/29/2007	7/20/2008	204	29
27	1/12/2008	6/19/2008	159	--
31	2/4/2008	5/30/2008	116	0
55	4/2/2008	4/3/2008	1	0
57	4/2/2008	4/3/2008	1	0
67	4/18/2008	6/3/2008	46	0
87	6/3/2008	7/10/2008	37	0
90*	6/3/2008	6/11/2008*	8	16
		7/10/2008	37	0
87	6/3/2008	4/23/2009	324	0
93	6/4/2008	7/4/2008	30	0
103	7/10/2008	7/23/2008	13	0
107	7/18/2008	7/27/2008	9	0
112	7/20/2008	7/23/2008	3	0
113	7/20/2008	7/23/2008	3	0
136	8/8/2008	9/4/2008	27	0
		9/28/2008	51	0
137	8/8/08	7/22/10*	713	10
159	10/10/2008	8/28/2009	322	28
184	5/8/2009	5/9/2009	1	0
	5/8/2009	6/1/2009	24	0
188	5/11/2009	8/11/2009	92	0
HK	5/15/2009	5/25/2009	10	0
	5/15/2009	6/25/2009	41	0
200	6/1/2009	6/25/2009	24	0
		7/9/2009	38	0
		8/11/2009	71	0
		10/1/2009	122	0
190	6/8/2009	6/20/2009	12	0
		7/10/2009	32	0
		7/21/2009	43	0
		8/28/2009	81	0
		10/7/2009	121	0
194	6/9/2009	8/4/2009	56	0
		9/1/2009	84	0
		10/13/2009	126	0
YS	6/17/2009	6/25/2009	8	0
197	7/3/2009	7/10/2009	7	0
		8/15/2009	43	15

Table 2. Number of specimens sampled by FWRI staff for DNA, otoliths, and/or gonads (2006-2010).

year	sample (n)	aged (n)	gonad histology (n)
2006	7	7	0
2007	4	4	1
2008	17	17	2
2009	7	0	0
2010	70	32	20
Total	105	60	23

Figures

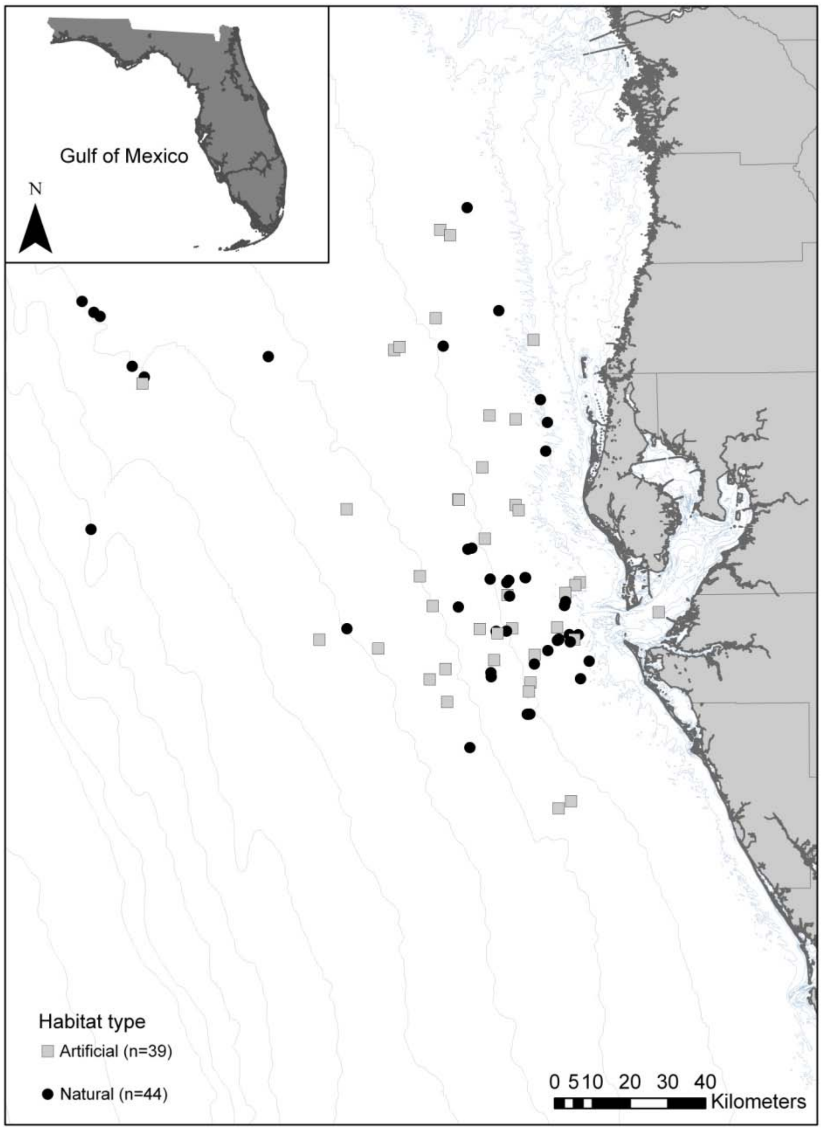

Fig. 1. Study area and sites surveyed for goliath grouper between October 2007 and May 2010. Surveys took place during all months of the year over artificial and natural habitat that ranged in depth from 7 – 48 m.

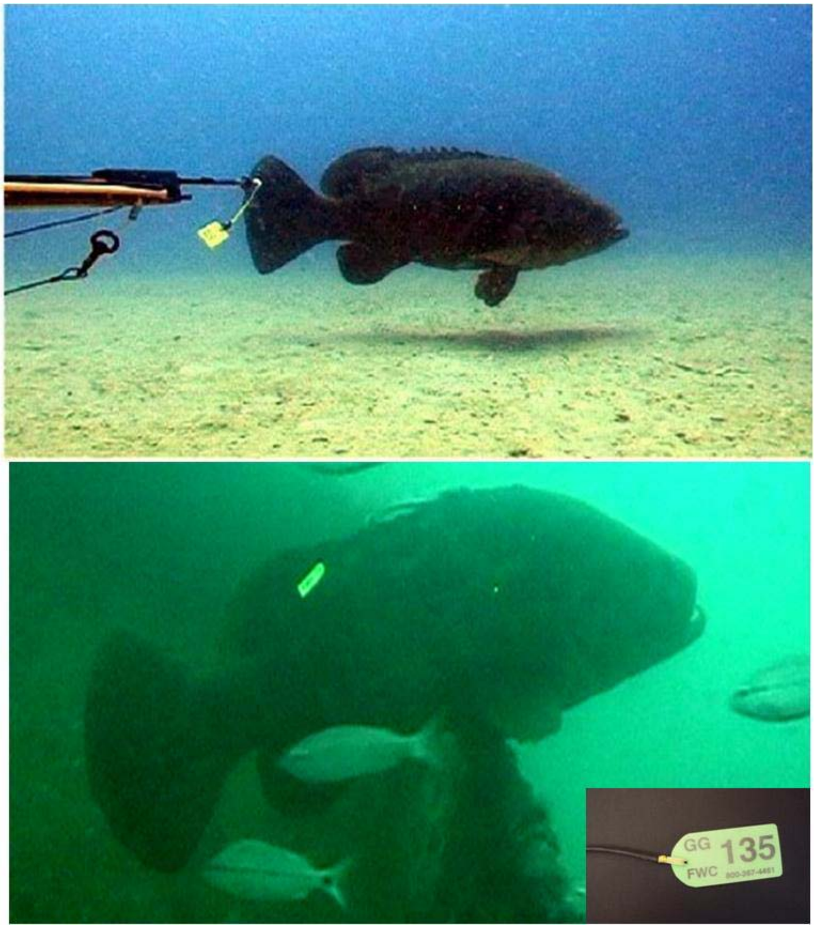

Fig. 2. External identification tag and placement on goliath grouper. Insert depicts close up of tag text and hotline information.

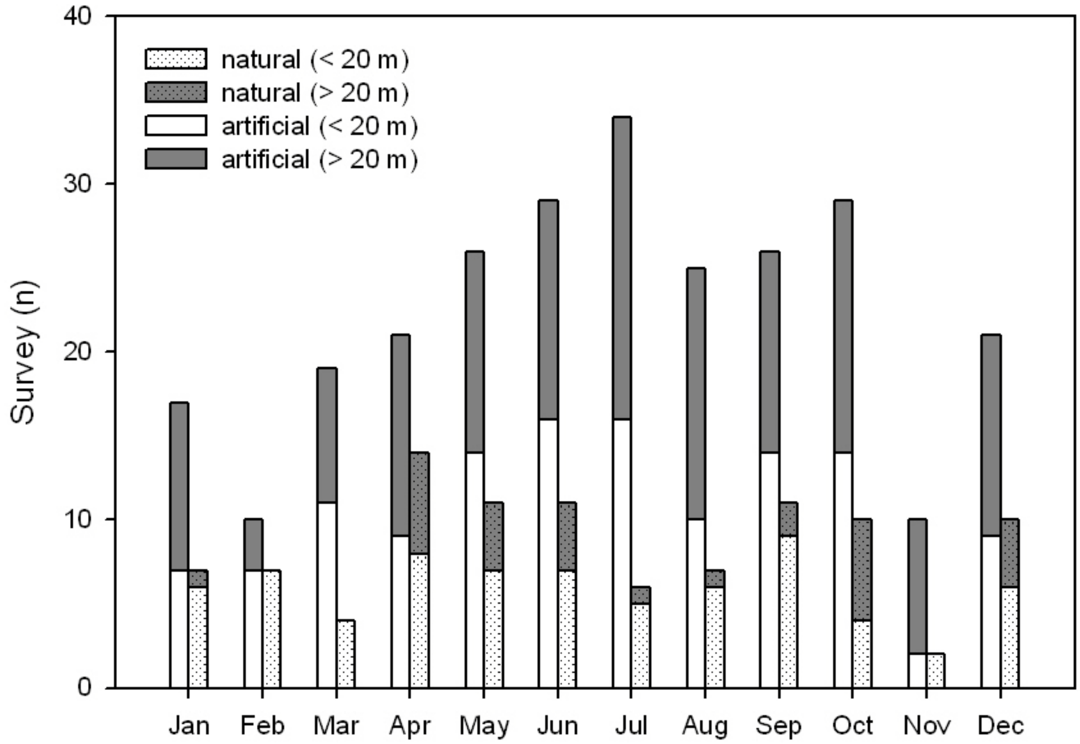

Fig. 3. Number of dive surveys per month and habitat type. Dark gray indicates surveys performed at sites > 20 m in depth.

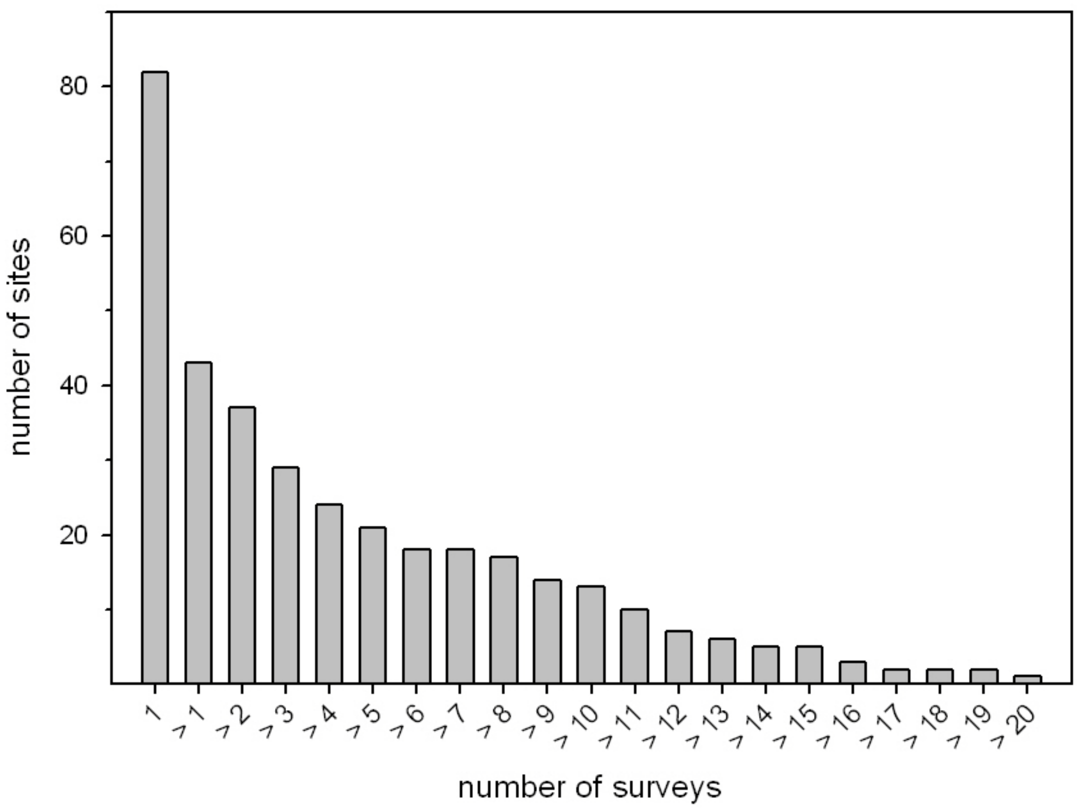

Fig. 4. Frequency of visits to sites within the survey area. Total number of sites surveyed at least once = 84.

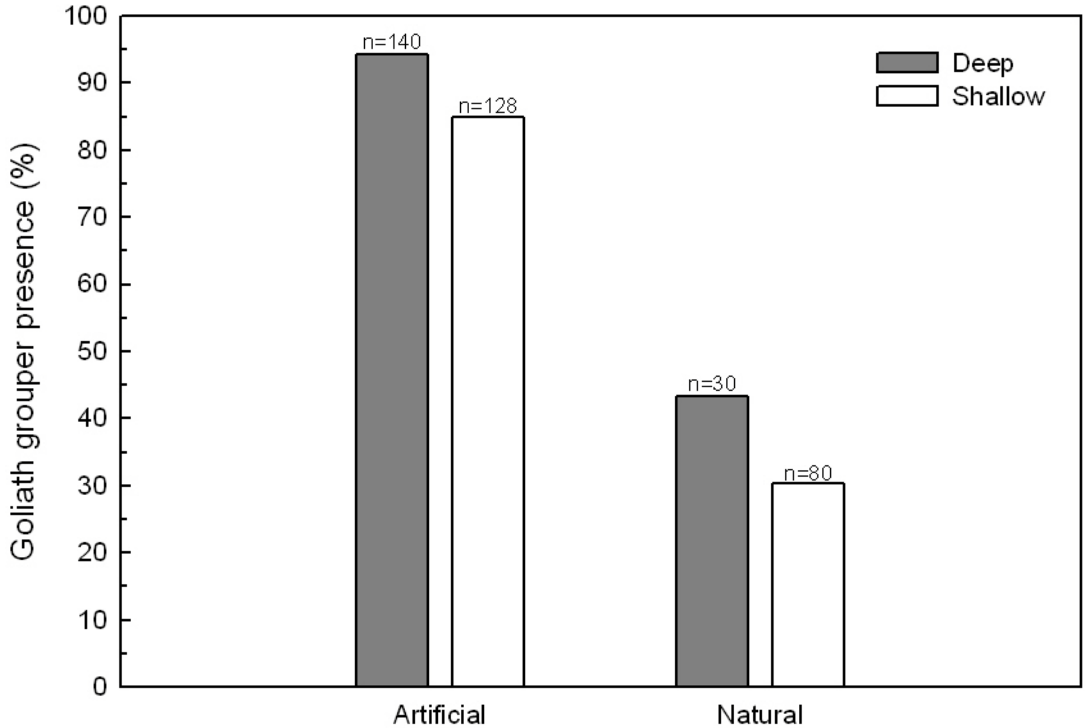

Fig. 5. Goliath grouper presence as the percentage of the total number of dive surveys, by depth range and habitat type. Deep sites are >20 m; shallow are ≤ 20 m. The total number of surveys (n) for each habitat/depth combination is shown above each bar.

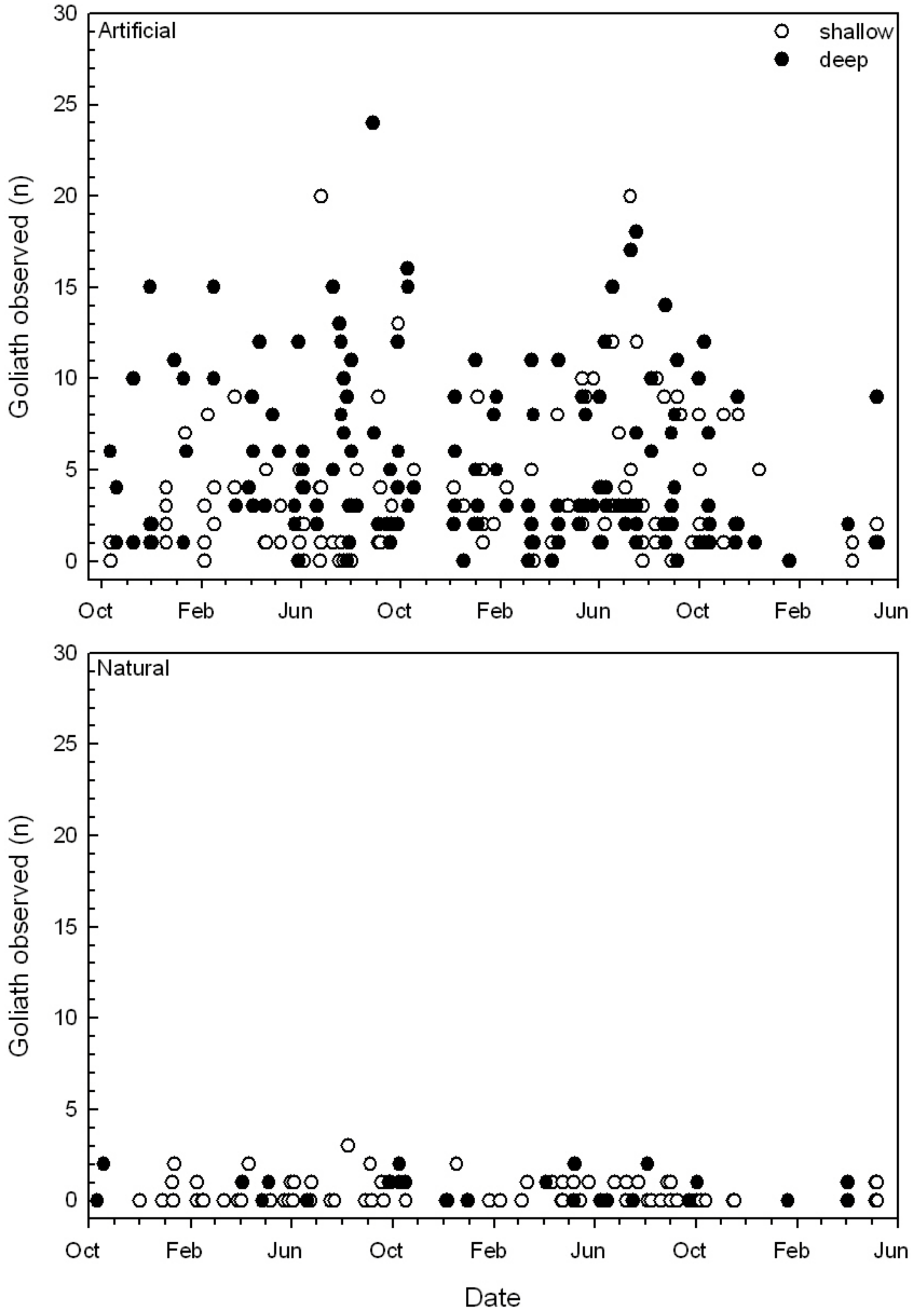

Fig. 6. Raw numbers of goliath grouper observed over artificial habitat (top) and natural habitat (bottom) throughout the study period (October 2007 through May 2010). Symbols indicate site depth as shallow (white circles; ≤ 20m) and deep (black circles; > 20m).

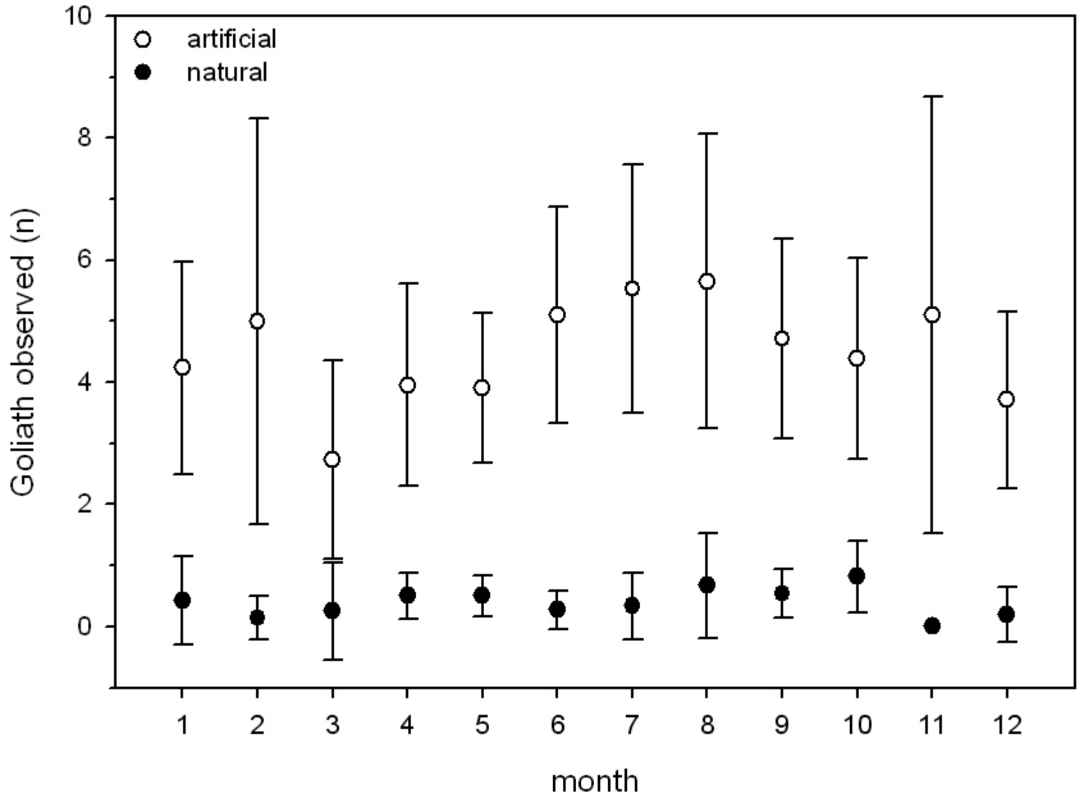

Fig. 7. Mean number of goliath grouper observed at artificial and natural habitat over all months. Error bars designate 95% confidence limits.

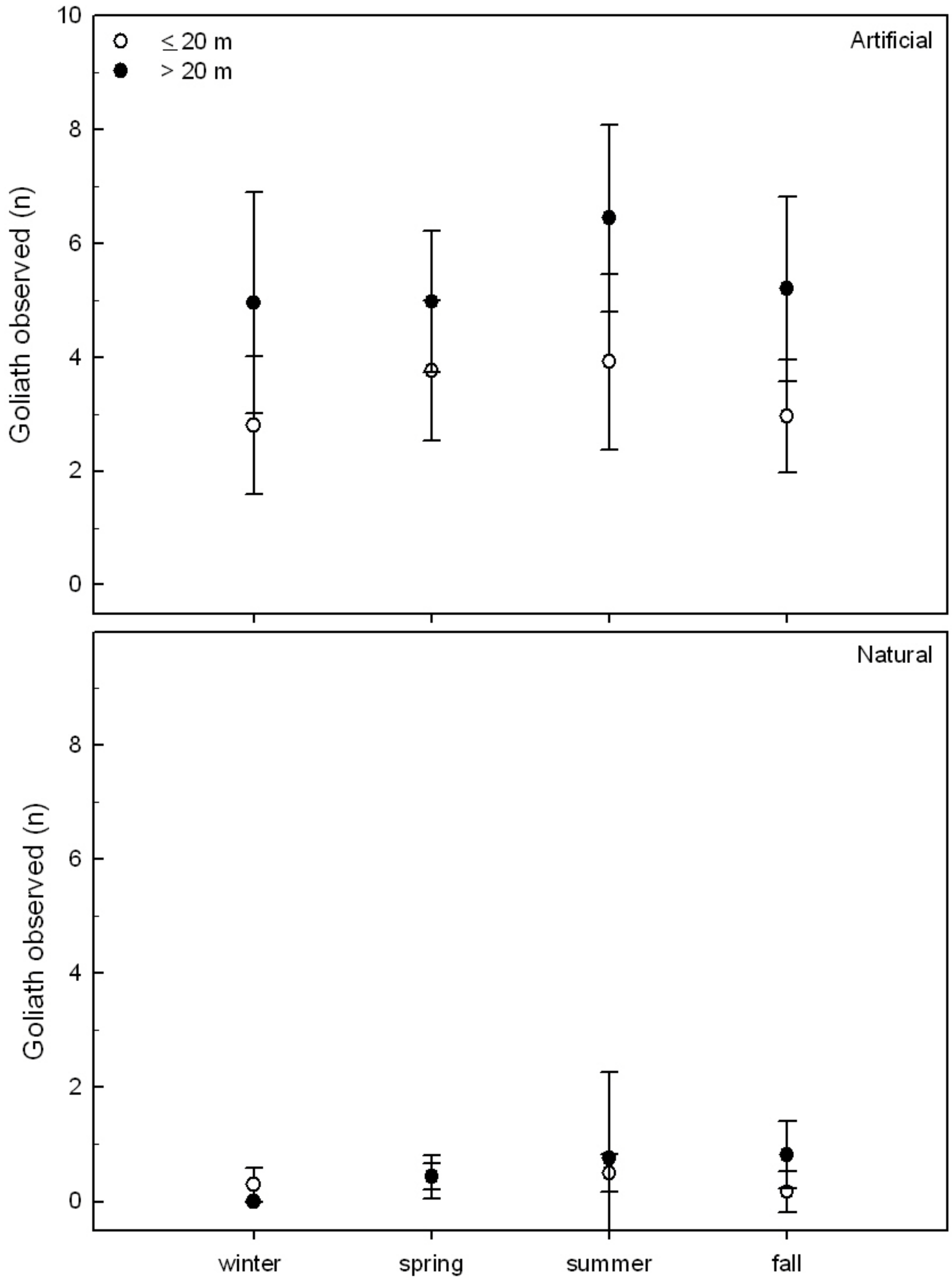

Fig. 8. Mean number of goliath grouper observed per season and depth range over artificial (top panel; 268 surveys) and natural (bottom panel; 110 surveys) habitat. Seasons are designated as winter (Jan – Mar), spring (Apr – Jun), summer (Jul – Sep) and fall (Oct – Dec). Error bars designate 95% confidence limits.

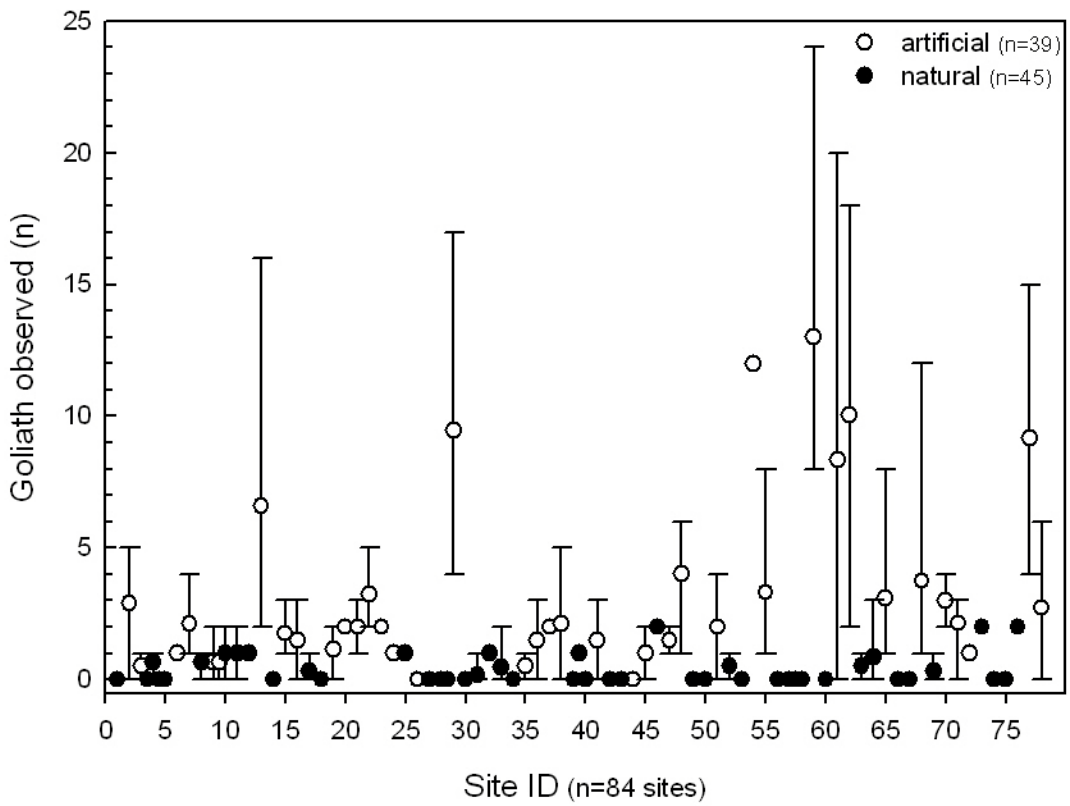

Fig. 9. Number of goliath grouper observed at each site during the study period (October 2007 – May 2010). Symbols represent mean abundance and error bars designate the maximum and minimum number observed at each site. Sites are numbered in order of decreasing latitude (i.e., site 1 is the northernmost site).Total number of surveys = 378.

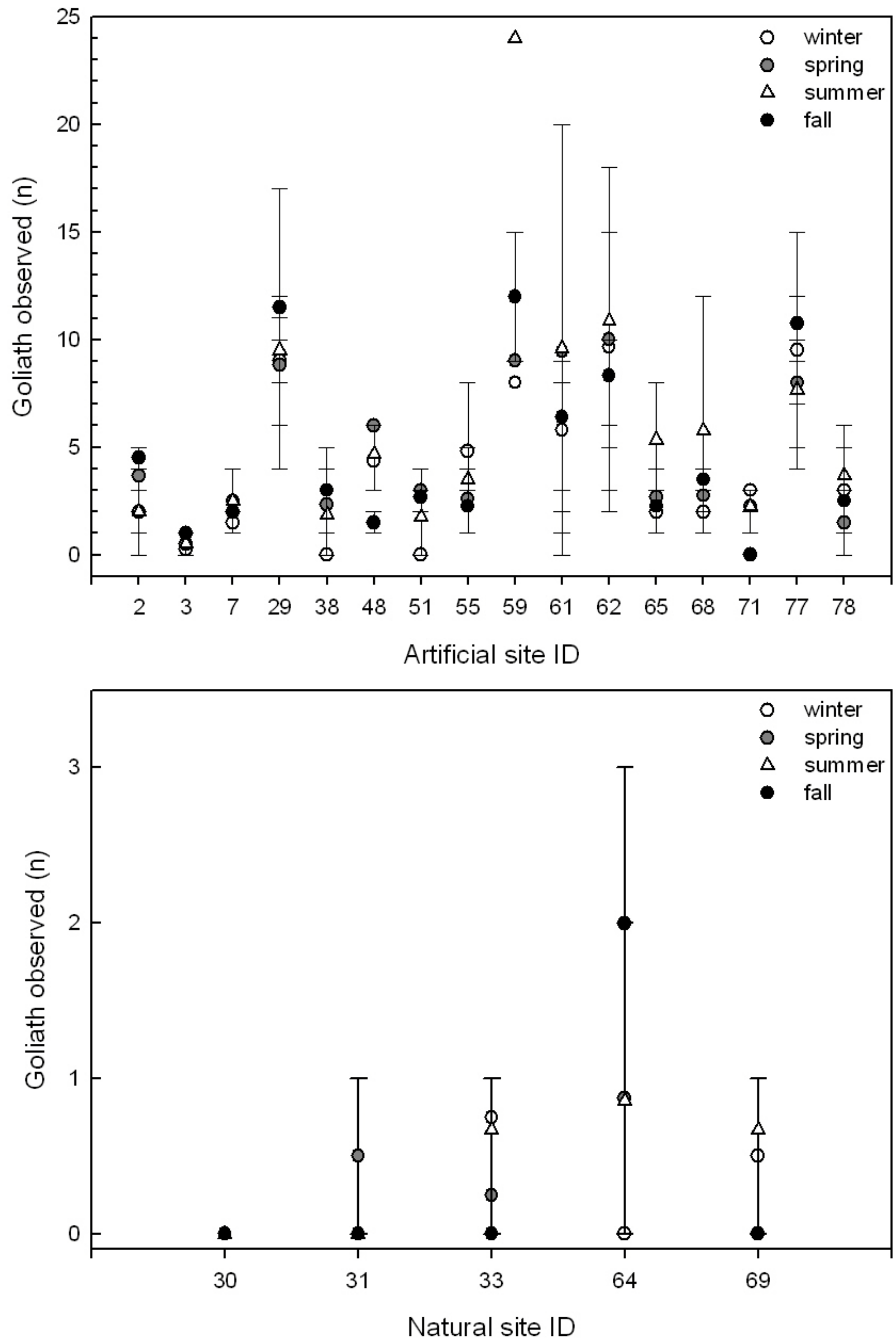

Fig.10. Mean number of goliath grouper observed at sites designated for seasonal sampling over artificial (n = 16; top panel) and natural (n=5; bottom panel) habitat. Sites were visited multiple times per season between October 2007 and May 2010. Seasons are designated as winter (Jan – Mar), spring (Apr – Jun), summer (Jul – Sep) and fall (Oct – Dec). Sites are numbered by latitude and ascend from north to south (i.e., site 2 is the northernmost site). Error bars represent the minimum and maximum number of goliath observed for each site and season.

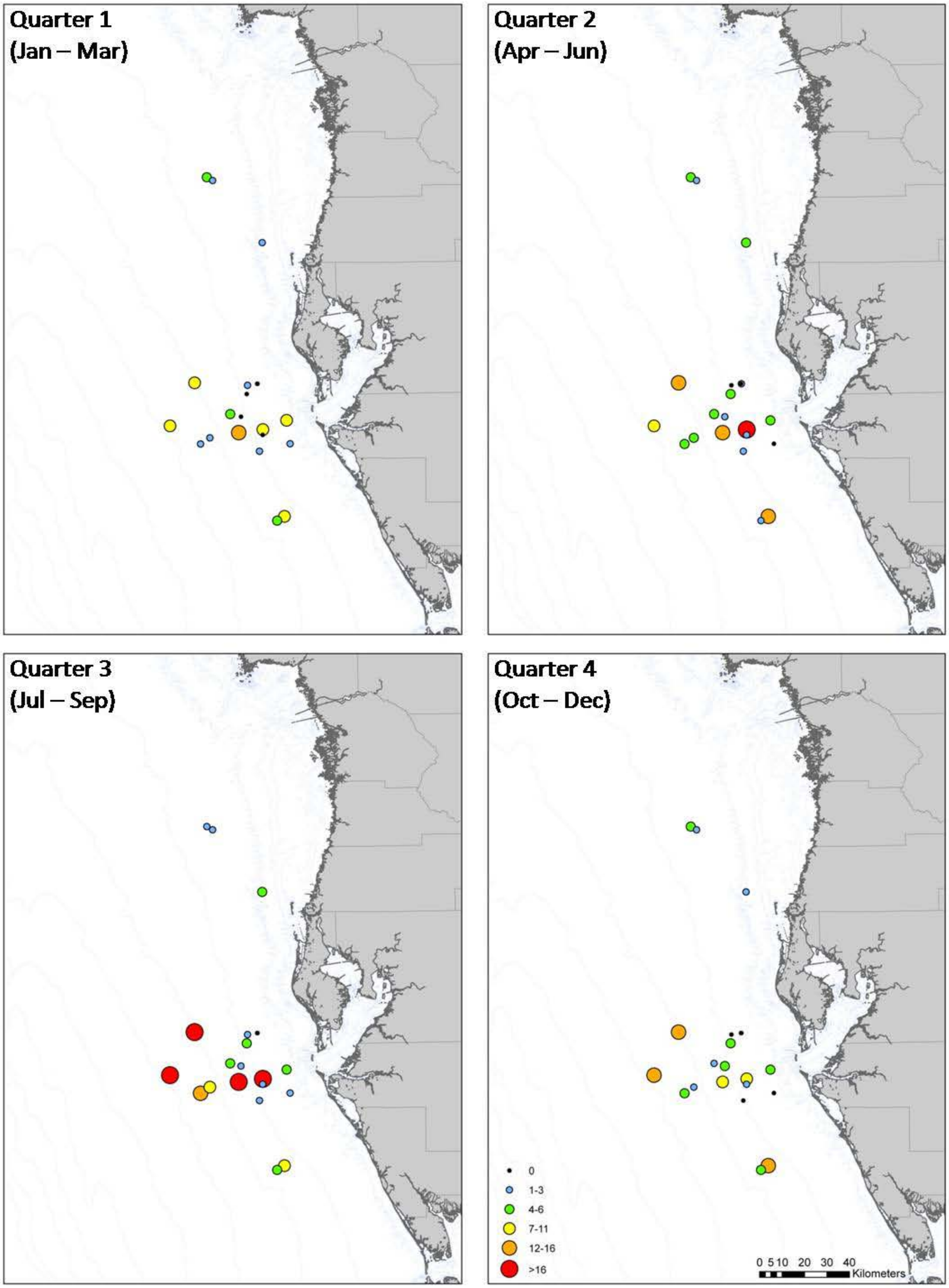

Fig. 11. Sites visited at least once per season. Number of surveys per site ranged 5 – 29. Maximum number of goliath observed per quarter is displayed.

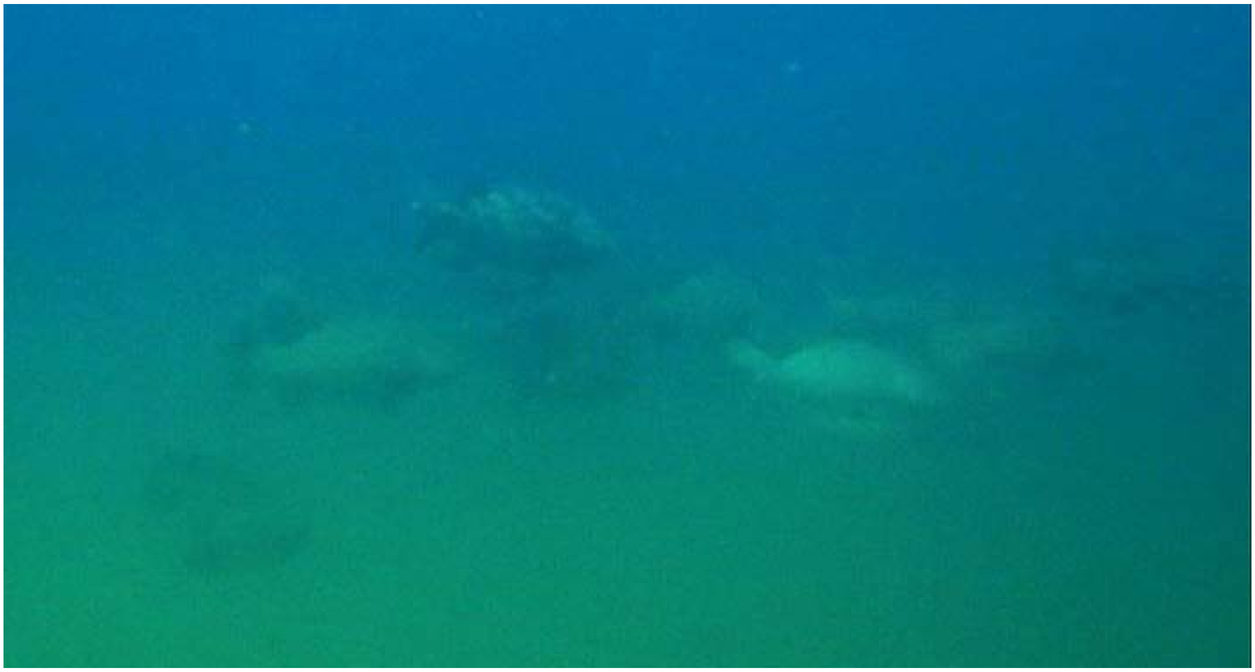

Fig. 12. Image of goliath grouper “stacking.” This behavior occurred in the water column (10 -25 feet off the bottom) during daylight hours and was observed during the spawning season at two of the study sites (shipwrecks). Image was taken as a still frame from video footage.

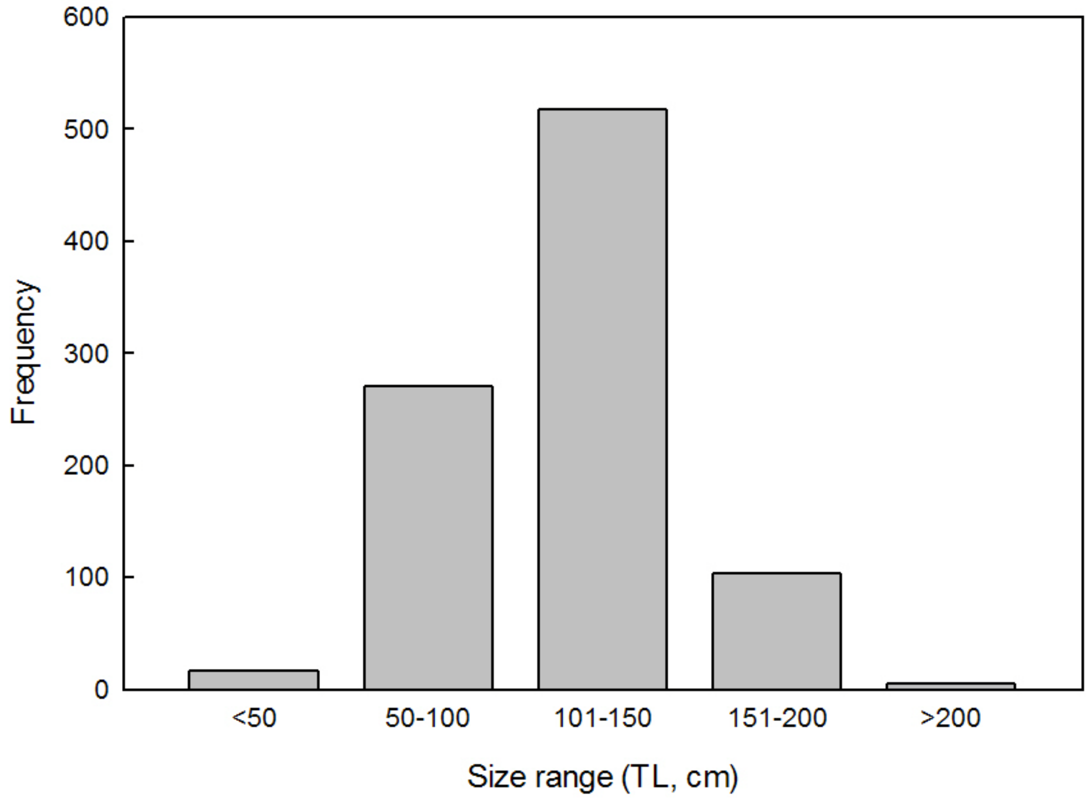

Fig. 13. Frequency histogram representing the size range of goliath grouper observed during the study period.

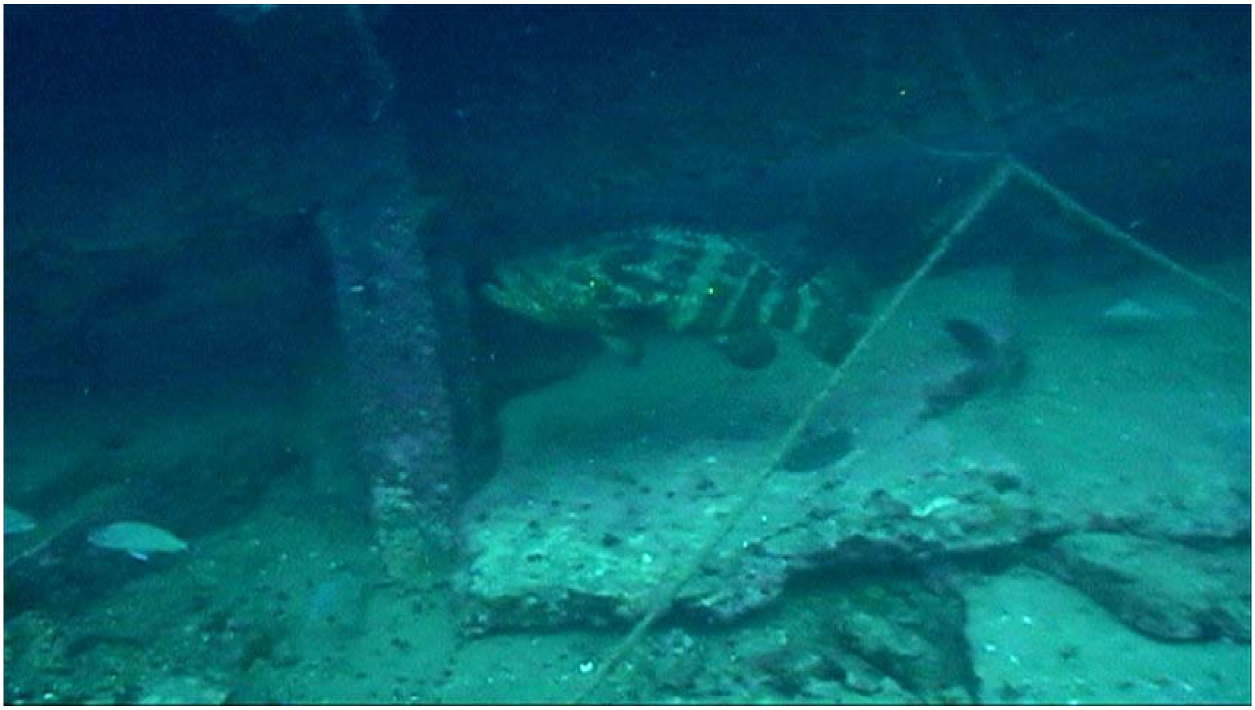

Fig. 14. Small fish (TL = 67 cm) observed offshore (80 km from shore, 36 m deep). Laser points are 20 cm apart.

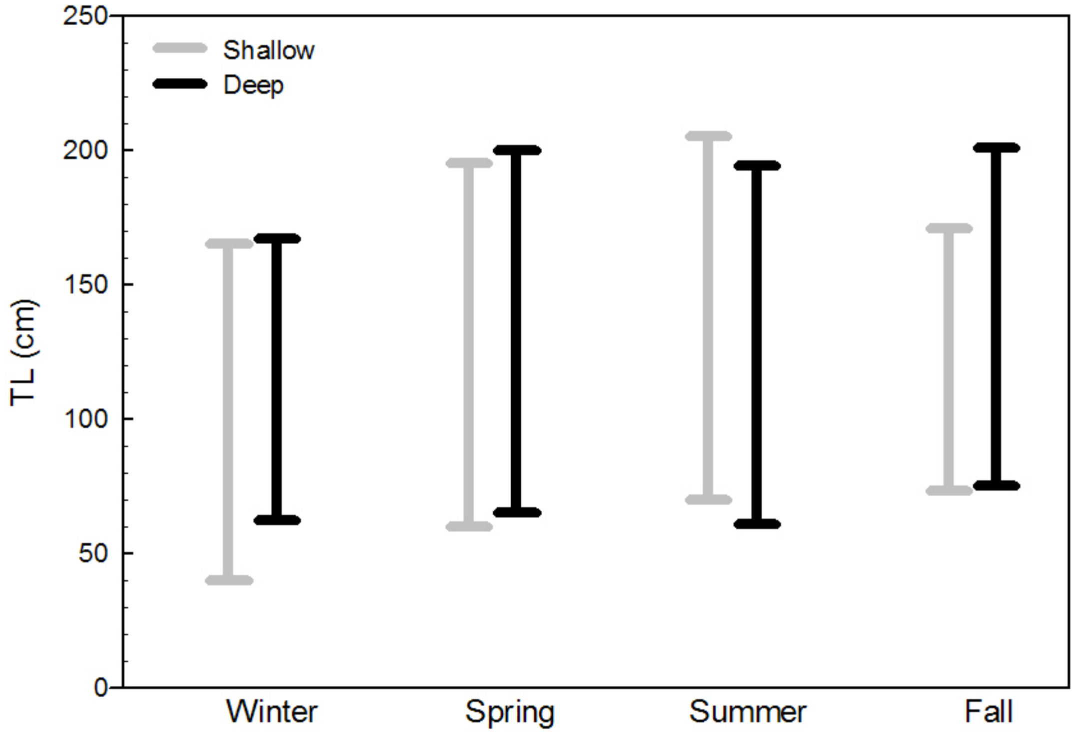

Fig. 15. Range of fish total lengths (TL) observed for each season and depth range. There was not a significant relationship between fish total length and season or depth.

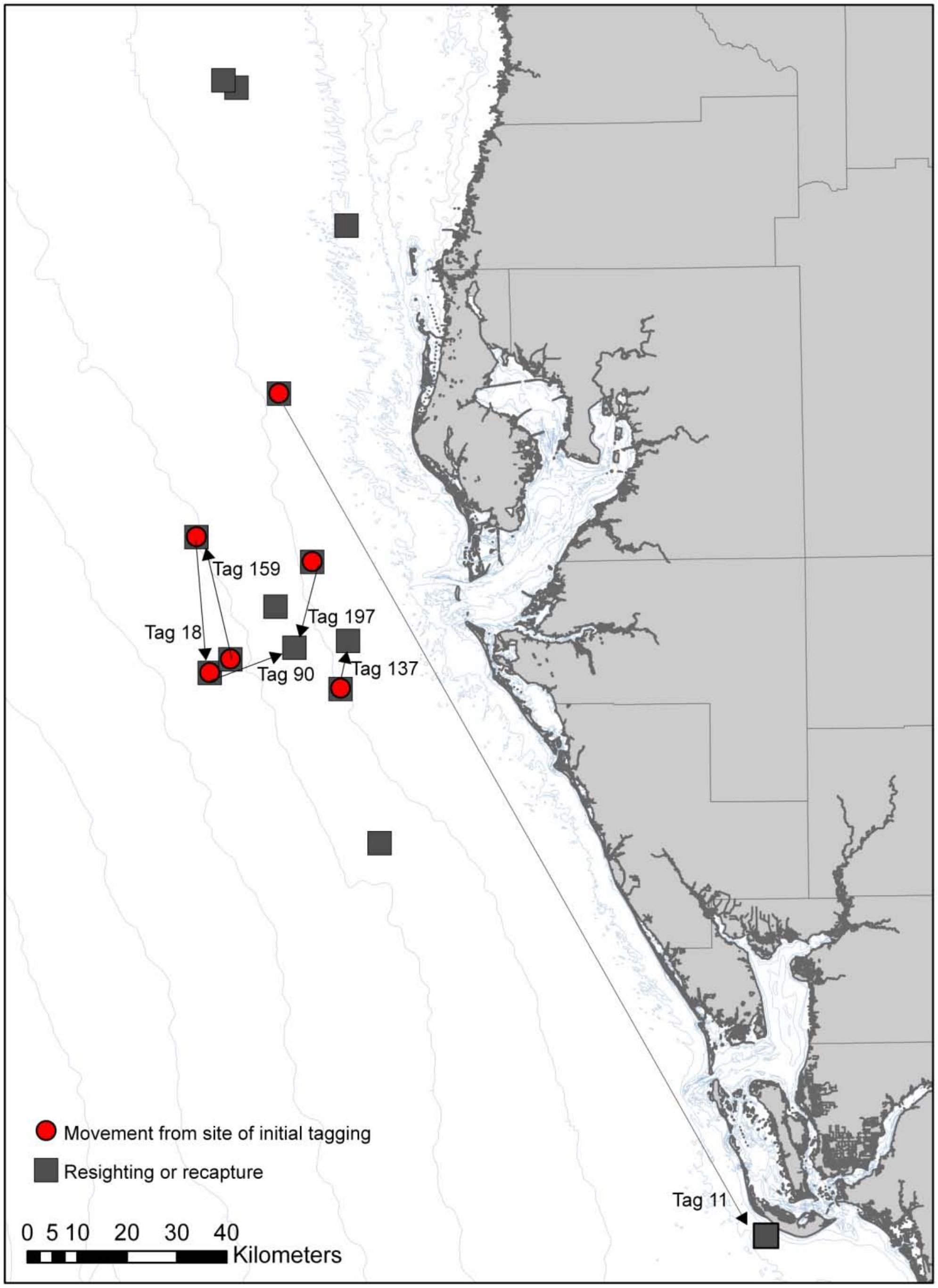

Fig. 16. Movement of tagged goliath grouper. The majority of individuals were resighted at the same location as the initial tagging event (grey squares indicate resighting locations). Movements up to 203 km were verified for six individuals (indicated by arrows and red circles; red circles = site of initial tagging).

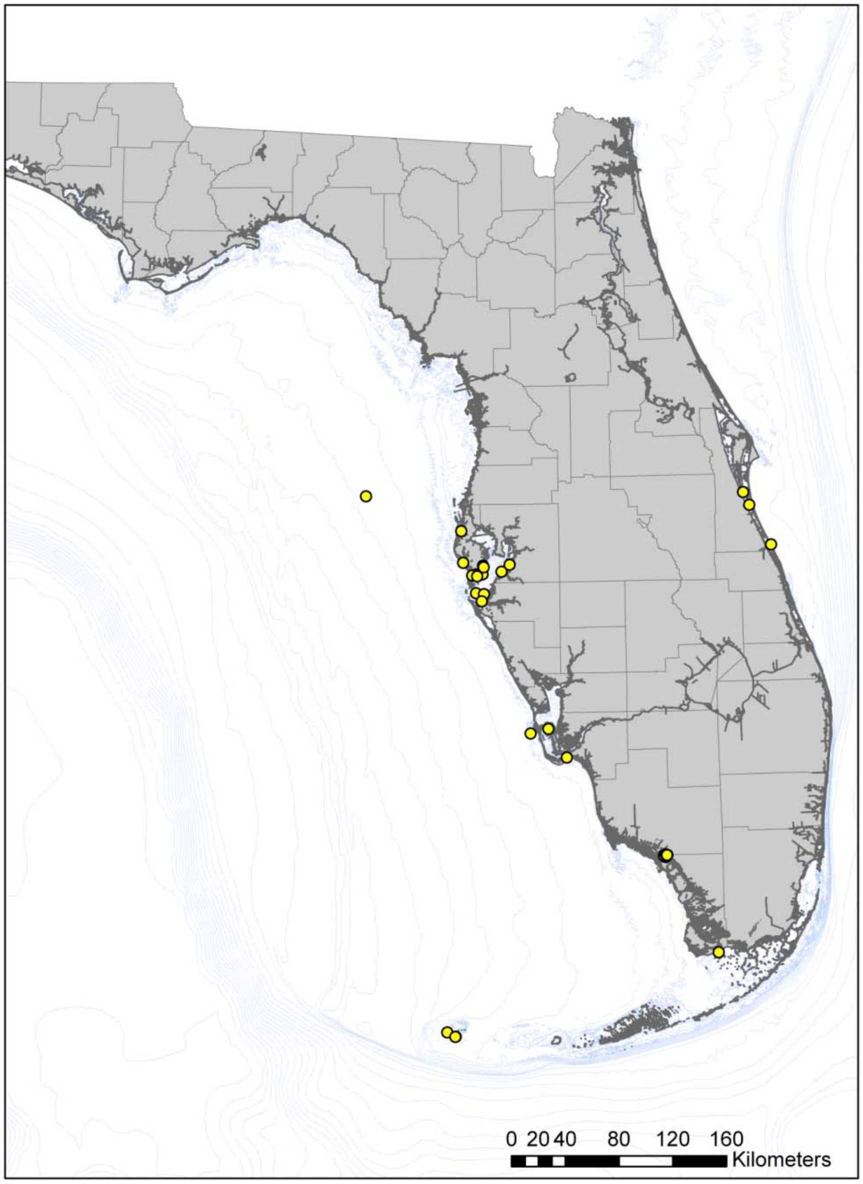

Fig. 17. Locations of opportunistic collections of goliath grouper (measurements, DNA, and/or life history samples) between 2006 and 2010.

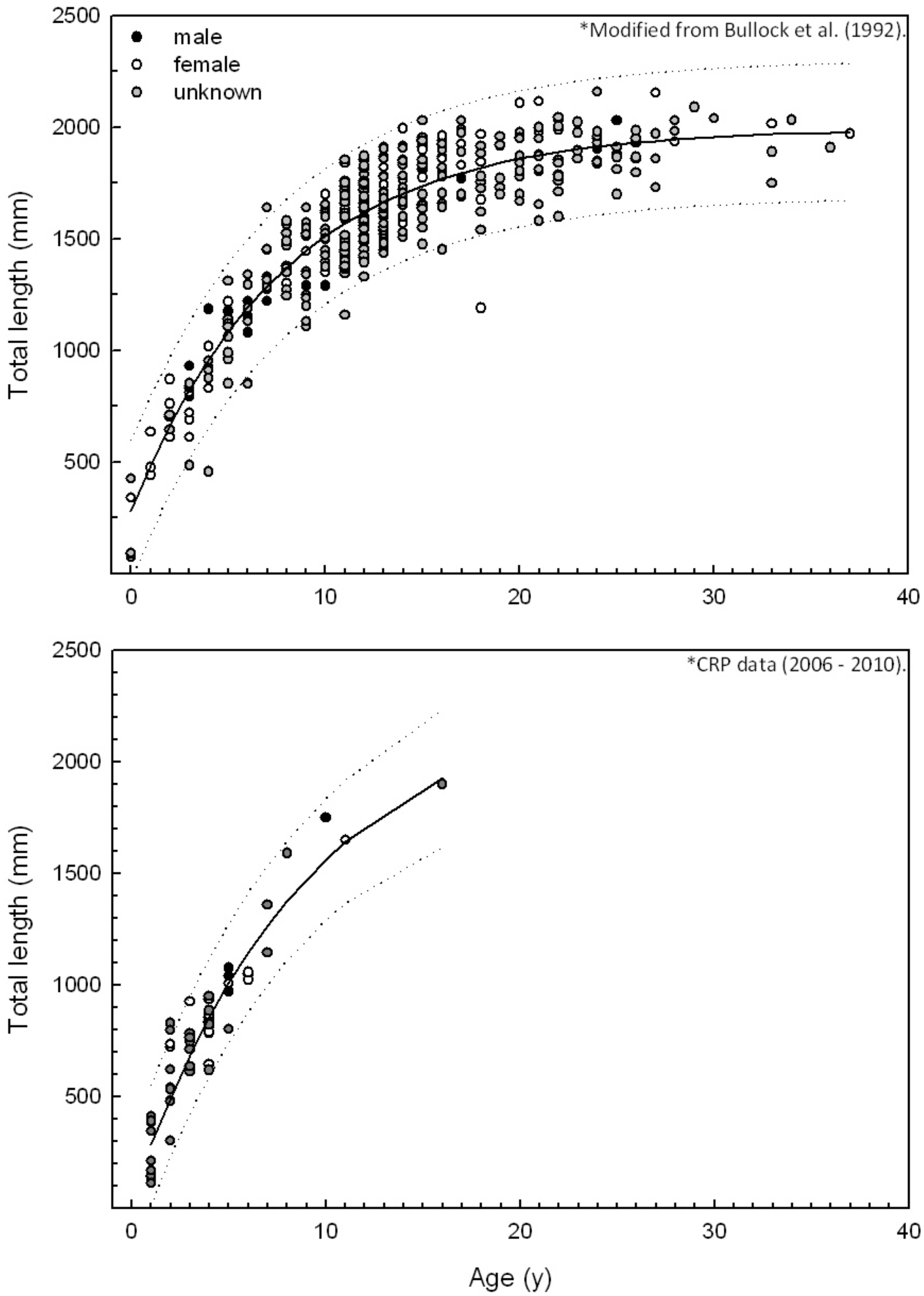

Figure 18. Length and age data for goliath grouper from Bullock et al. (1992) (top; n=382) and the current CRP research (bottom; n=60). The solid line represents the predicted length at age (x). Dotted lines indicate 95% confidence limits. Fish sex is indicated by symbol color (black = male, white = female, gray = unknown).

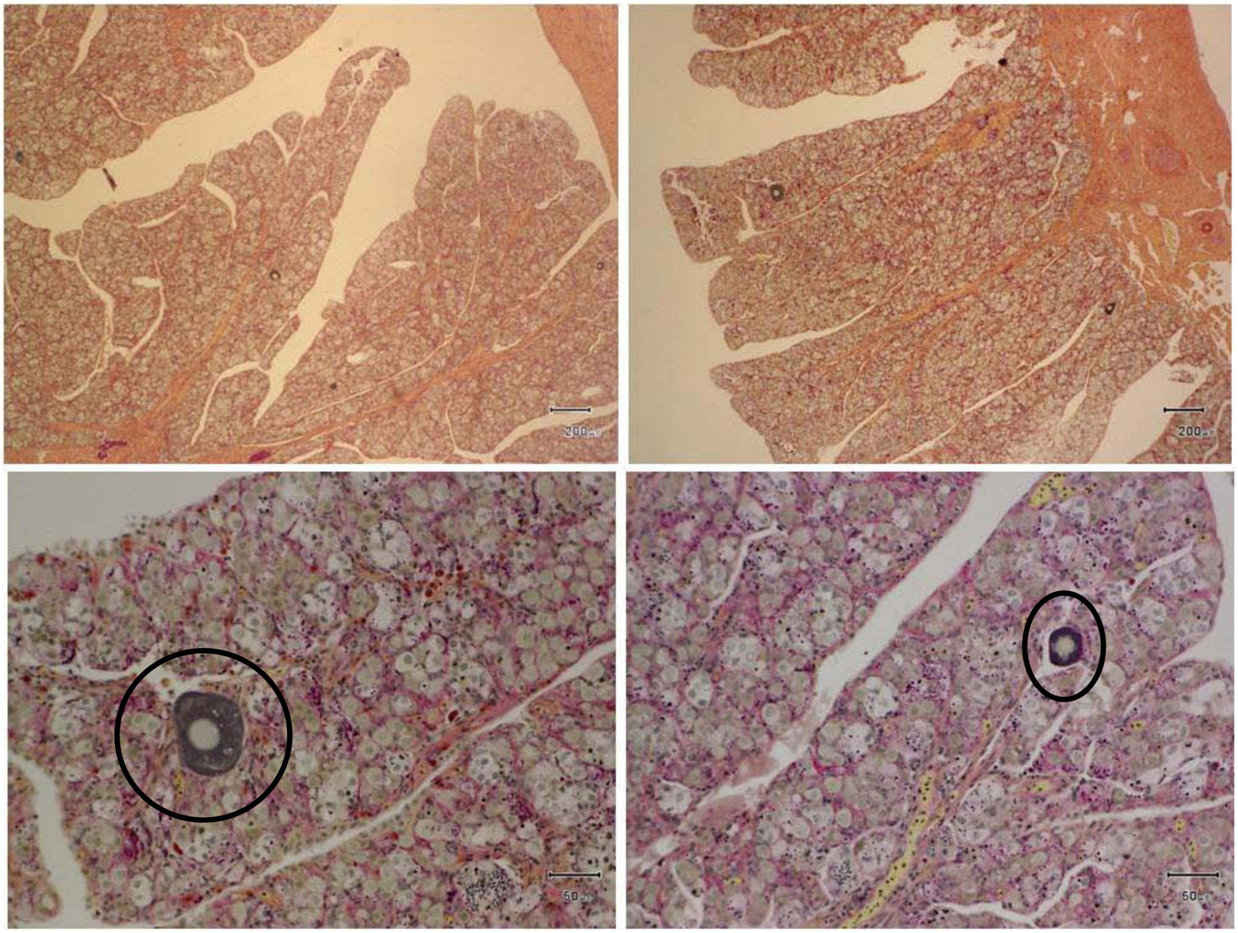

Fig. 19. Histology images for male goliath grouper with primary growth oocytes (circled) present within the gonad.