fishes

MDPI

Article

Absolute Abundance Estimates of Atlantic Goliath Grouper (*Epinephelus itajara*) on Spawning Aggregation Sites

James V. Locascio [1,*], Christopher C. Koenig [2] and Christopher R. Malinowski [3]

[1] Mote Marine Laboratory and Aquarium, 1600 Ken Thompson Parkway, Sarasota, FL 34236, USA
[2] Coastal & Marine Laboratory, Florida State University, 3618 Coastal Highway, St. Theresa, FL 32358, USA; ckoenig@fsu.edu
[3] Ocean First Institute, 51 Shoreland Dr, Key Largo, FL 33037, USA; chris@oceanfirstinstitute.org
* Correspondence: locascio@mote.org

Abstract: Reliable data on Atlantic Goliath Grouper abundance are prerequisite to informed management decisions, particularly as the State of Florida reopened a limited harvest on the species in 2023 after a 32-year moratorium. Limited data exist for this purpose and fisheries data have been unavailable for over three decades due to a fishery closure that began in 1990. The purpose of this study was to compare absolute abundance estimates of Goliath Grouper between two years using an efficient, cost-effective method developed by Koenig. An underwater tagging method was used to collect mark and resight data for use in a Peterson deterministic model. These data were collected at the same spawning aggregation sites off Jupiter, Florida near the time of the new moon in September 2013 and August 2022. We found that Goliath Grouper abundance had declined at all but one of six sites since 2013. Because data were not collected during the intervening years, interannual variability is unknown. However, given the highly age-structured spawning stock of adult Goliath Grouper on the spawning grounds, the lower abundances measured in 2022 may reflect a real decline in the population rather than just representing a weak year of adult recruitment to these spawning sites.

Keywords: Goliath Grouper; population estimate; spawning aggregation; Peterson model

Key Contribution: An underwater tagging method was used to generate data for the Peterson mark and resight deterministic model to estimate absolute abundance of Goliath Grouper at spawning aggregation sites. The results indicate the method is valid and that a significant decline in abundance of Goliath Grouper may have occurred between 2013 and 2022 on verified spawning sites off the Southeast Florida Coast.

check for updates

Citation: Locascio, J.V.; Koenig, C.C.; Malinowski, C.R. Absolute Abundance Estimates of Atlantic Goliath Grouper (*Epinephelus itajara*) on Spawning Aggregation Sites. *Fishes* **2023**, *8*, 394. https://doi.org/10.3390/fishes8080394

Academic Editor: Alexandra Almeida Silva

Received: 31 March 2023
Revised: 21 July 2023
Accepted: 24 July 2023
Published: 30 July 2023

1. Introduction

The Atlantic Goliath Grouper (*Epinephelus itajara*)—hereafter referred to as Goliath Grouper—is a large and iconic fish species that is broadly distributed in coastal tropical and subtropical waters of the Atlantic Ocean from the southeastern US, throughout the Caribbean to Brazil. Goliath Grouper form spawning aggregations of up to about 100 individuals on offshore rocky reefs and shipwrecks. The dominant spawning times in Florida (USA) are around the new moons of August, September, and October. Pelagic larval duration may last up to 80 days before settlement in mangrove detrital habitat [1]. The species relies on red mangrove (*Rhizophora mangle*) habitat until it is approximately five years of age and 1.0 m in length, and then it migrates to offshore adult habitat [2].

After decades of commercial harvest, the Goliath Grouper fishery was closed in Federal and State waters of the United States (USA) in 1990. While it remains closed in Federal waters, a limited recreational harvest of 200 juveniles per year was approved in Florida beginning in 2023. Opinions do vary over the quality and quantity of available data to adequately inform management decisions. Indeed, peer reviewers rejected three different Goliath Grouper stock assessments conducted in 2004, 2011, and 2016 because of data

and modeling deficiencies [3–5]. Evidence of Goliath Grouper population recovery is based both on diver and angler encounters as well as on scientific data [6]. While divers, anglers, and scientists can agree that the population has experienced a degree of recovery since the moratorium was implemented, they do not agree on the extent of the recovery, the impacts the recovery has on other fisheries and ecosystems, or to what degree the species remains vulnerable to poaching, catch-and-release discard mortality, habitat loss and degradation, increasingly frequent and severe red tide events, and episodic severe cold weather events [6].

The purpose of this study was to establish a reliable and cost-effective method of generating data to estimate the absolute abundance of Goliath Grouper on spawning sites during the spawning season in Florida waters. An underwater tagging method was used that did not require catching fish by hook-and-line and so could be conducted with minimal disruption to the aggregation. The deterministic Peterson model was used to estimate abundance from mark and recapture data. This method can be used at traditional spawning aggregation sites alone or in combination with other methods (i.e., acoustics) to create time series of behavior and abundance of Goliath Grouper during the critical life history stage of reproduction.

2. Materials and Methods

Mark and resight efforts were conducted near the time of the new moon (+/−4 days) during September 2013 and August 2022. This time period was targeted because it is when reproductive output is highest, and therefore Goliath Grouper densities would be greatest [7–9], based on evidence from egg collection (genetically verified), gonad histology, acoustic telemetry data and increased levels of sound production associated with courtship and spawning [7–10]. In 2013 and 2022, fish were tagged at the MG111, Zion Train, Esso Bonaire, Sun Tug, and 208 wreck sites, and at one natural, hard bottom site known as 3 Holes (Figure 1). The Zion Train is located approximately 200 m south of the Esso Bonaire. Due to their proximity, these two sites are treated both independently and collectively (as a complex) in the methods and data analysis. All study sites had previously been confirmed as spawning aggregation sites based on passive acoustic recordings, with the exception of the 208 wreck at which passive acoustic recordings were not made [7–9].

Figure 1. Locations of Atlantic Goliath Grouper *Epinephelus itajara* spawning aggregation sites off the coast of Jupiter, Florida (USA), where population estimates were made in September 2013 and August 2022. The inset in the upper right corner provides a geographic reference.

The tag consisted of a billfish tag head with a 6″ stainless steel wire connected to a 1″ diameter laminated disk tag (Floy Tag & Mfg. Inc., Seattle, WA, USA). The billfish tag was placed on a modified applicator tip of a low-power spear gun. The tags were applied at very close range which implants the tag head subdermally near the origin of the second dorsal fin. The wire leader and numbered disk portion of the tag remained external so it could be seen by divers during resight surveys [10]. All fish were tagged by the same diver (Captain Don Demaria, Summerland Key).

The new moon occurred on 5 September in 2013. Goliath Grouper were tagged on 6 September and resighted at each site on 7 September 2013. In 2022, the new moon occurred on 27 August and Goliath Grouper were tagged on 23 and 24 August and resighted on 24–26 August 2022. Because time allowed, a second dive was made to resight tagged fish at MG111 on 25 August 2022. Resighting tagged fish on multiple consecutive days gave us the opportunity to observe whether an increase in Goliath Grouper occurred leading up to the new moon. Abundance estimates were calculated individually and cumulatively for the Zion Train and Esso Bonaire sites, which together form the Zion Train complex, previously reported by Koenig et al. [7,8] as Zion South and Zion North.

The Peterson model assumes that marked and unmarked fish have an equal probability of being resighted. It also assumes a closed population which for the purpose of this study meant that fish remain on the same site between the time they are tagged and resighted. These assumptions were confirmed in the original work by Koenig [10]. To address the first assumption, Koenig et al. [7,8,10] used 3 divers to conduct a roving diver technique (RDT) one day after fish were tagged and demonstrated that the proportion of marked to unmarked fish was similar among divers which met the assumption of random assortment and therefore an equal chance of tagged fish being sighted. The second assumption was addressed using acoustic telemetry data which showed low movement (<10% of tagged fish) between spawning sites near the time of the new moon [8,11].We assumed these conditions also held for our 2022 surveys.

During both years of the study between two and five divers were used per dive to collect resight data one to three days after tagging. The Peterson model allows for sampling with replacement so tagged and untagged fish can be resighted multiple times during the survey. Ecological Methodology software version 7.4 University of British Columbia, Vancouver, B.C., Can. [12] was used to model the population size within 95% confidence limits using the Wilson binomial distribution [13]. The Peterson model is deterministic and uses the number of fish tagged at Time 1, the total number of fish sighted at Time 2, and the total number of marked fish sighted at Time 2 as input. The total number of fish sighted and the total number of marked fish sighted by each diver were summed per dive and used to estimate abundance with the following equation:

$$N = T(C + 1)/(R + 1); \quad (1)$$

where T = total number of fish tagged at Time 1, C = total number of fish counted (both tagged and untagged) at Time 2, and R = the total number of tagged fish counted at Time 2.

3. Results

The absolute abundance of Goliath Grouper was estimated at all sites in 2013 and again in 2022 with the exceptions of the 208 and Sun Tug wreck sites. This was because only one Goliath Grouper was observed in 2022 at the 208 wreck and the majority of the structure that was exposed in 2013 was covered with sand in 2022. The Sun Tug had just three Goliath Grouper on it in 2022, only one of which was tagged. Since the model requires a minimum of three tagged individuals abundance estimates were not possible at these two sites in 2022.

Estimates of Goliath Grouper absolute abundance were lower at all sites in 2022 and significantly so at the Esso Bonaire, Zion Train complex, and MG111. The abundance estimate made at Zion Train, as an individual site, was significantly lower after the first day of tagging (24 August 2022) than in 2013 but increased to levels close to those measured

in 2013 on the following two days (24 August 2022 and 25 August 2022). Similarly, at 3 Holes, abundance was significantly lower on the first day of resighting compared to 2013 data (24 August 2022) but increased slightly on 26 August 2022. Abundance estimates increased at each site on the days leading up to the new moon, but not significantly so. The results of tagging effort, population estimates, and confidence intervals are given in Table 1. Population estimates by site and day are plotted in Figure 2A–E.

Table 1. Spawning aggregation sites off Jupiter, FL (USA) where Atlantic Goliath Grouper *Epinephelus itajara* were tagged and resighted during this study. 3-HOLES = natural habitat. All other sites are artificial reefs. Zion Train complex = Zion Train and Esso Bonaire sites. CI = confidence interval of the estimated population size. n = number of tagged fish, number of resighted tagged fish, or total number of tagged and untagged fish sighted. N = population size (based on Equation (1) in the text). Grey areas indicate that the same tagged fish were sighted in each resighting event. N/A for the Sun Tug and 208 Wreck are due to too few fish observed and tagged to produced a population estimate.

	Tagged Fish		Resighted Tagged Fish		Total Tagged and Untagged Fish	Population Size	
Study Site	**Date**	**n**	**Date**	**n**	**n**	**Estimate N**	**95% C.I**
3-HOLES	9/6/2013	13	9/7/2013	11	49	54	36–110
	8/23/2022	9	8/24/2022	24	43	16	13–23
			8/26/2022	11	37	29	19–57
ESSO BONAIRE	9/6/2013	12	9/7/2013	17	109	73	50–128
	8/24/2022	3	8/25/2022	7	11	5	3–10
			8/26/2022	7	21	8	5–21
ZION TRAIN	9/6/2013	12	9/7/2013	11	67	70	45–146
	8/23/2022	13	8/24/2022	27	82	39	29–57
			8/25/2022	24	139	73	53–114
			8/26/2022	27	167	78	57–119
ZION TRAIN COMPLEX	9/6/2013	24	9/7/2013	28	176	147	109–221
	8/23–24/2022	16	8/26/2022	34	188	70	53–106
MG111	9/6/2013	42	9/7/2013	46	192	173	137–254
	8/23/2022	6	8/24/2022	19	98	30	21–50
	8/23–24/2022	15	8/25/2022	17	57	48	35–81
			8/25/2022	12	31	37	26–69
			8/26/2022	33	157	70	53–101
SUN TUG	9/6/2013	8	9/7/2013	19	57	23	17–37
	8/24/2022	1	8/25/2022	N/A	N/A	N/A	N/A
208 WRECK	9/6/2013	17	9/7/2013	37	47	23	20–30
	8/24/2022	1	8/25/2022	N/A	N/A	N/A	N/A

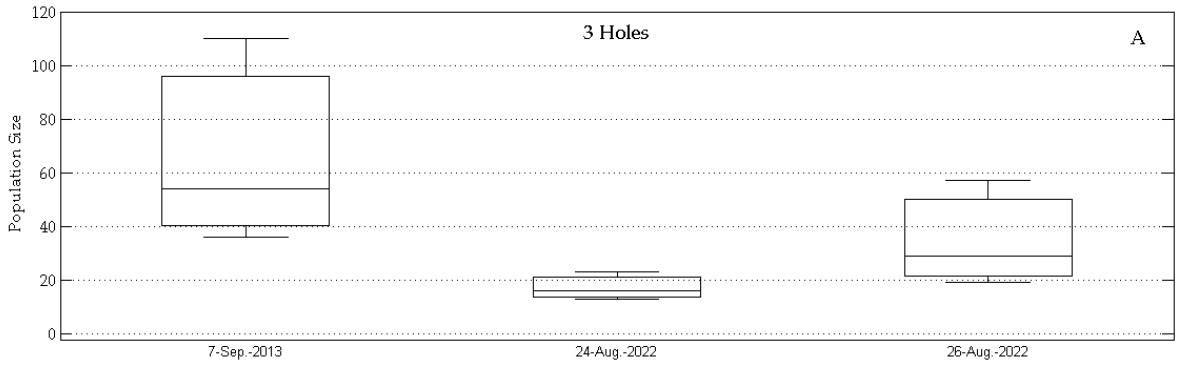

Figure 2. *Cont.*

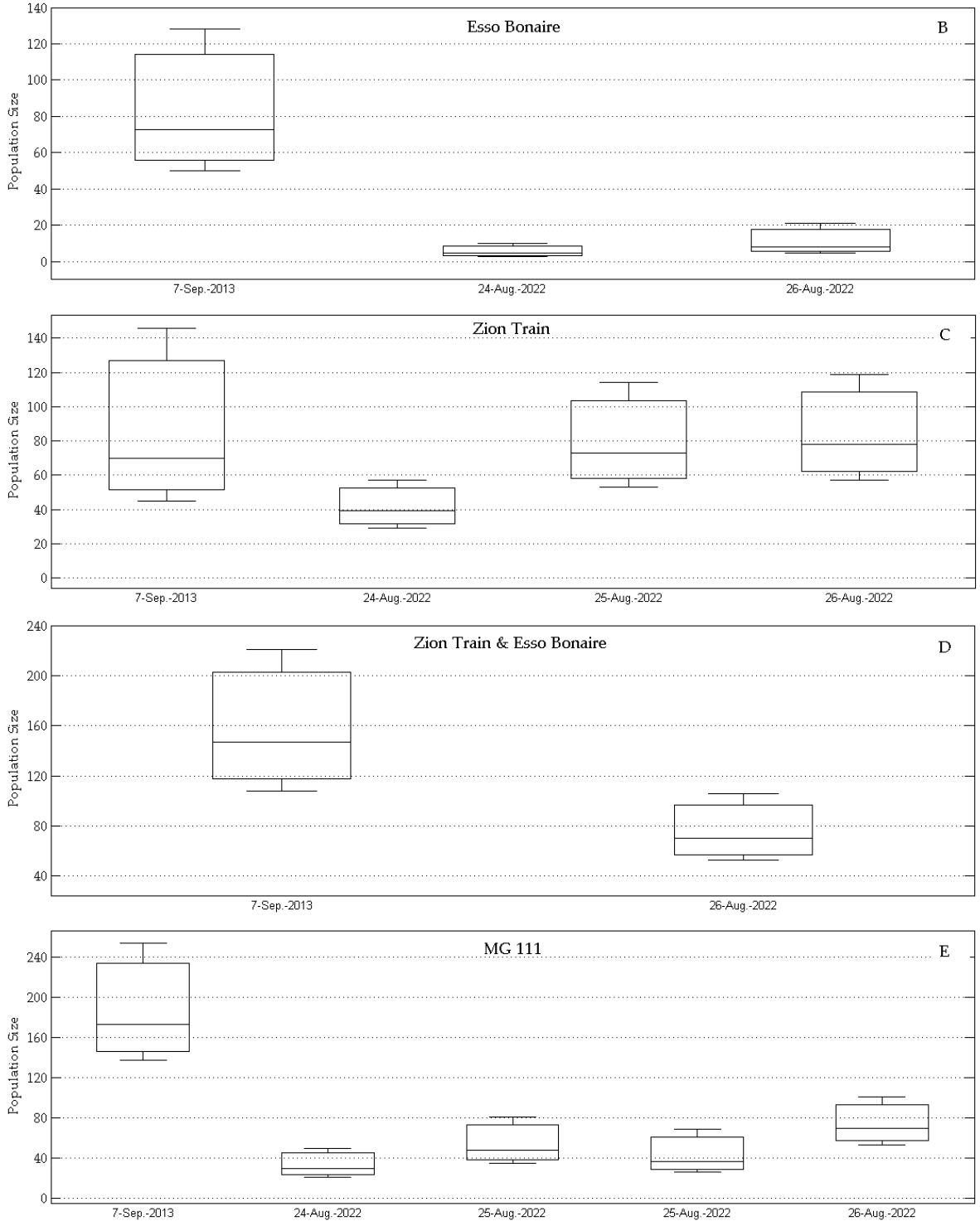

Figure 2. Atlantic Goliath Grouper (*Epinephelus itajara*) population size estimates made at spawning aggregation sites off Jupiter, Florida (USA) in 2013 and 2022. Error bars indicate the upper and lower 95% confidence interval about the population estimate indicated by the horizontal bar within the box. (**A**) 3 Holes wreck; (**B**) Esso Bonaire; (**C**) Zion Train wreck in 2013 and 2022. (**D**) Zion Train complex (Zion Train and Esso Bonaire combined) in 2013 and 2022. (**E**) MG111 in 2013 and 2022.

4. Discussion

The purpose of this study was to compare absolute abundance estimates of Goliath Grouper made in 2013 and 2022 at the same primary spawning aggregation sites off Jupiter, Florida. Abundance estimates of Goliath Grouper were significantly lower at each site in

2022 with the exception of the Zion Train when evaluated separately from the Esso Bonaire and 3 Holes if using only the 24 August 2022 data. A comparison between years for the Sun Tug was not possible because too few fish were tagged in 2022 (one of three observed) to use the Peterson model; however, in 2013 eight fish were tagged at this site and the population size was estimated at 23 individuals. This demonstrates an obvious decline in abundance despite not meeting the model requirements of at least three tagged fish. Population estimates at the 208 wreck were also not possible in 2022 because the site was largely covered over by sand and essentially abandoned by Goliath Grouper, yet in 2013 17 fish were tagged at this site and the population was estimated at 23 individuals. It is unknown at what point this site became covered with sand and whether fish that used this site traditionally moved to other local sites.

Because reference data were only collected in 2013 we do not have measurements of variability during the intervening 8 years and so trend analysis of the population was not possible. However, in 2012 Koenig found that the ages of Goliath Grouper on the same spawning sites used in this study ranged from 6 to 15 years (total length ranged from 102 cm–225 cm) with the majority concentrated between 9 and 12 years of age [7,8]. These data confirm that the population was highly age structured. Age-structured spawning populations tend to be more stable over time and demonstrate lower levels of interannual variability because multiple year classes contribute to the population [14,15]. If the age structure found in 2012 was consistent over the period between sampling years it would support the idea that the decline in abundance of Goliath Grouper measured in 2022 is real and not just due to lower numbers of adults attending spawning sites. Further support for this was demonstrated by a sharp decline in tag attrition rate (i.e., as apparent mortality) between 2013 and 2015 for fish tagged with acoustic transmitters on the sites used in this study [16]. The possibility also exists that Goliath Grouper redistributed themselves among other spawning sites that were not included in the 2022 study, but if this were the case we would not have expected all of the sites we monitored to have lower abundance estimates in 2022. Additional contributions to a decline in the Goliath Grouper population at these sites may include catch and release mortality including recreational and shallow water commercial bottom long-lining, poaching, and episodic cold events like in 2010 which severely impacted the juvenile population and therefore the adults population in following years.

The tagging method was feasible because Goliath Grouper can be closely approached by divers and the principal spawning aggregation sites where this study was conducted are in relatively shallow, clear water (<30 m). We used a single, expert diver/tagger for both the 2013 and 2022 surveys. If more than one skilled diver were used the number of tagged fish would presumably increase as would the precision of abundance estimates.

Using telemetry data, Koenig and Coleman [8], Ellis [16], and Locascio [17] found low movement of Goliath Grouper among spawning sites, with about 90% remaining on site during the spawning season. Some movement was observed among the closely co-located spawning aggregation sites MG111, Zion Train, and Sun Tug [8,16,17]. Thus it is important that these sites as well as the natural hard bottom sites of 3 Holes and Gary's Greys—both frequently used by Goliath Grouper during the spawning season [16,17]—are included among the sites off Jupiter that are monitored contemporaneously to obtain the most accurate estimate of Goliath Grouper population size.

5. Conclusions

Because of a 32-year moratorium on commercial harvest fisheries, data do not exist to estimate stock–recruitment [18] or spawning potential ratios required for stock assessment of Goliath Grouper. The methods used in this study represent a relatively cost-effective way to reliably estimate Goliath Grouper abundance on spawning aggregation sites when and where they occur in highest densities. In light of our results, which show an overall significant decline in absolute abundance of Goliath Grouper on several primary spawning sites near Jupiter, Florida, and because the Florida Fish and Wildlife Conservation Commis-

sion has decided to open a limited recreational take of juveniles in 2023, we recommend the continued monitoring of Goliath Grouper absolute abundance on spawning aggregation sites using the methods presented to support informed management decisions.

Author Contributions: For this study, J.V.L. and C.C.K. provided resources, validated data, and conducted the formal analysis. C.C.K., J.V.L. and C.R.M. contributed to conceptualization, field studies, and methodology. C.C.K. and J.V.L. provided funding. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by two awards to Mote Marine Laboratory (J Locascio), one as NOAA MARFIN project number NA15NMF4330152 and the other from the Sierra Club and two awards to Florida State University (CC Koenig and FC Coleman) from the National Oceanic and Atmospheric Association (NOAA) MARFIN project numbers NA05NMF4540045 and NA10NMF4330123.

Institutional Review Board Statement: Florida State University certified research methods through IACUC (Institutional Animal Care and Use Committee) (protocol numbers 1106 and 1411 to CC Koenig and FC Coleman); Mote Marine Laboratory IACUC committee approved Goliath Grouper research methods for Locascio via permit 22-03-JL2, 28 March 2022.

Data Availability Statement: Data from this study are available through Mote Marine Laboratory.

Acknowledgments: Field support for this project was provided by Don Demaria for fish tagging, Captain Mike Newman for vessel support, and Mikki McComb-Kobza (Ocean First Institute) for assistance with field work.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Lara, M.R.; Schull, J.; Jones, D.L.; Allman, R. Early life history stages of goliath grouper (*Epinephelus itajara*) (Pisces: *Epinephelidae*) from Ten Thousand Islands, Florida. Endanger. *Species Res.* **2009**, *7*, 221–228. [CrossRef]
2. Koenig, C.C.; Coleman, F.C.; Eklund, A.M.; Schull, J.; Ueland, J. Mangroves as essential nursery habitat for goliath grouper (*Epinephelus itajara*). *Bull. Mar. Sci.* **2007**, *80*, 567–585.
3. SEDAR (Southeast Data, Assessment, and Review Cooperative). SEDAR 6 Stock Assessment Report, Southeastern U.S. Goliath Grouper. 2004. Available online: https://sedarweb.org/assessments/sedar-06/ (accessed on 2 March 2023).
4. SEDAR (Southeast Data, Assessment, and Review Cooperative). SEDAR 23 Stock Assessment Report, Southeastern U.S. Goliath Grouper. 2011. Available online: https://sedarweb.org/assessments/sedar-23/ (accessed on 2 March 2023).
5. SEDAR (Southeast Data, Assessment, and Review Cooperative). SEDAR 47 Stock Assessment Report, Southeastern U.S. Goliath Grouper. 2016. Available online: https://sedarweb.org/assessments/sedar-47/ (accessed on 2 March 2023).
6. Koenig, C.C.; Coleman, F.C.; Malinowski, C.R. Atlantic Goliath Grouper of Florida: To Fish or Not to Fish. *Fisheries* **2020**, *45*, 20–32. [CrossRef]
7. Koenig, C.C.; Coleman, F.C. Population Density, Demographics, and Predation Effects of Adult Goliath Grouper. NOAA MARFIN Project NA05NMF4540045. 2009. Available online: https://www.reef.org/ (accessed on 3 March 2023).
8. Koenig, C.C.; Coleman, F.C. *Regional Age Structure, Reproductive Biology and Trophic Patterns of Adult Goliath Grouper in Florida*; NOAA MARFIN Project NA11NMF4330123; University of Florida: Gainesville, FL, USA, 2016.
9. Mann, D.A.; Locascio, J.V.; Coleman, F.C.; Koenig, C.C. Goliath Grouper (*Epinephelus itajara*) sound production and movement patterns on aggregation sties. Endanger. *Species Res.* **2009**, *7*, 229–236. [CrossRef]
10. Koenig, C.C.; Coleman, F.C.; Kingon, K. Pattern of recovery of the goliath grouper *Epinephelus itajara* population in the southeastern US. *Bull. Mar. Sci.* **2011**, *87*, 891–911. [CrossRef]
11. Koenig, C.C.; Bueno, L.S.; Coleman, F.C.; Cusick, J.A.; Ellis, R.D.; Kingon, K.; Locascio, J.V.; Malinowski, C.R.; Murie, D.J.; Stallings, C.D. Diel, lunar and seasonal spawning patterns of the Atlantic Goliath Grouper, *Epinephelus itajara*, off Florida, United States. *Bull. Mar. Sci.* **2017**, *93*, 91–406. [CrossRef]
12. Krebs, C.J. *Ecological Methodology*, 2nd ed.; software V. 7.4, 2019; Benjamin/Cummings, the University of California: Riverside, CA, USA, 1999; p. 620.
13. Brown, L.D.; Cai, T.T.; DasGupta, A. Interval Estimation for a Binomial Proportion. *Stat. Sci.* **2001**, *16*, 101–133. [CrossRef]
14. Berkeley, S.A.; Hixon, M.A.; Larson, R.J.; Love, M.S. Fisheries Sustainability via Protection of Age Structure and Spatial Distribution of Fish Populations. *Fisherie* **2004**, *29*, 23–32. [CrossRef]
15. Brunel, T.; GerJan, P.J. Is age structure a relevant criterion for the health of fish stocks? *ICES J. Mar. Sci.* **2013**, *70*, 270–283. [CrossRef]
16. Ellis, R.D.; Koenig, C.C.; Locascio, J.; Malinowski, C.; Coleman, F. Spawning migrations of the Atlantic Goliath Grouper. *Fishes* 2023, *in review*.

17. Locascio, J.V.; Binder, B.; Boswell, K. *Integration of Acoustic Methods for Assessing Goliath Grouper Spawning Aggregations*; MARFIN Final Report Project NA15NMF4330152; University of Florida: Gainesville, FL, USA, 2023.
18. Beverton, R.J.; Holt, S.J. *On the Dynamics of Exploited Fish Populations*; Series II; United Kingdom Ministry of Agriculture and Fisheries: London, UK, 1957; p. 19.