v1: 26 April 2024

Research Article

Estimates of Western Atlantic Goliath Grouper (Epinephelus itajara) Bycatch Mortality in Commercial Fisheries of the Southeastern United States from 2002 to 2022

Preprinted: 19 March 2024
Peer-approved: 26 April 2024

Qeios, Vol. 6 (2024)
ISSN: 2632-3834

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The Atlantic Goliath Grouper (*Epinephelus itajara*) in the southeastern United States is in decline due to increasingly large and persistent red tides, loss of juvenile habitat, and severe cold-weather events. In this paper, we address another source of mortality -- bycatch, focusing on data from NOAA Fisheries logbooks for commercial fisheries operating between 2002 and 2022. We calculate capture-related mortality based on known patterns of depth-related barotrauma drawn from the literature and assume that all fish captured at depths greater than 30 m died if unvented prior to release. The overall result suggests that 75% (14,124 of 18,770) of Goliath Grouper captures died from barotrauma, as they either hemorrhaged or were unable to return to the bottom because of increased buoyancy due to expanded gas trapped in the swim bladder. While fishers currently use self-reporting to document these mortalities, this approach often results in biases toward lower capture and a higher survival rate. Thus, we strongly urge the Florida Fish and Wildlife Conservation Commission and the National Oceanic and Atmospheric Administration to quit using logbook data and instead require that fishers use paid observers and remote electronic monitoring on all commercial and charter vessels to ensure more effective, timely, and reliable bycatch data for this and other protected species.

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Introduction

Commercial, charter, and recreational fisheries can be lethal to incidental captures—known as ‘bycatch.’ Whether it is or not depends on the type of gear used, the handling time, the depth of capture, and whether the bycatch can descend to the bottom independently. Forced rapid ascents of fish with a closed gas bladder cause gas expansion that can burst the swim bladder as ambient pressure decreases. Depth of capture, then, becomes an important consideration in the survival of fishes hauled from high ambient pressure environments (deep water) to low ambient pressure environments (the surface). This paper addresses bycatch of the western Atlantic goliath grouper (*Epinephelus itajara*)– hereafter referred to as goliath grouper – the largest reef fish in the region, reaching lengths of 2.5 m[1]. While distributed throughout the Gulf of Mexico and the eastern seaboard to North Carolina, most of these fish are found in the eastern Gulf of Mexico and the Atlantic seaboard of the State of Florida (Figure 1).

Figure 1. Map of the southeastern seaboard of the United States indicating the primary distribution of the western Atlantic Goliath grouper *Epinephelus itajara* populations. *Developed by FC Coleman in 2024.*

Goliath grouper approached extinction in the southeastern United States (SEUS) by the late 1980s, leading the National Oceanic and Atmospheric Administration (NOAA) and the State of Florida to protect them by 1990. Both overfishing and the loss of mangroves, the primary juvenile habitat, contributed to this decline[2]. Limited recovery occurred in the 20 years following the closure, although this was not the event that prompted the International Union for Conservation of Nature (IUCN) to change its listing from "critically endangered" in all parts of its western Atlantic range in 2011[3], to "vulnerable" in 2018. This change resulted from a modification in data interpretation rather than a change in population status[4].

The goliath grouper population is now suffering yet another decline[5][6]. Contributing factors include red tides, continued loss of essential juvenile habitat, severe cold-weather events (which tropical species like goliath grouper, snook (*Centropomis undecimalis*), and others cannot withstand[5]); and bycatch by commercial, charter, and recreational fisheries. Add to this a directed fishery for juveniles that opened in Florida in March 2023[5], and bycatch mortality becomes an even greater concern.

Estimating capture-release mortality is difficult because of the range of factors that contribute to it, including hook-induced tissue damage, depth of capture, and fisher handling time. To these, we add predation on exhausted fish post-release and improper or lack of venting. Venting is a practice used by fishers to release gas confined in the swim bladder of fish reeled to the surface rapidly from depth. It involves inserting a syringe or trocar-cannula through the body wall into the swim bladder, releasing the gas confined therein, and allowing the fish to descend to the bottom[7]. [8] have been strong proponents of educating fishers in the use of these devices. They conducted a study on fish descent after capture by hook-and-line, primarily focusing on red grouper (*Epinephelus morio*), and demonstrated that 60% of the fish captured could not descend when taken from water depths as shallow as 18 m (Figure 2). Unvented fish typically float on the surface after release if captured at depths greater than 30 m[9]. If they float for extended periods, they experience damage to their eyes and skin from the sun and are highly vulnerable to predation. Most die.

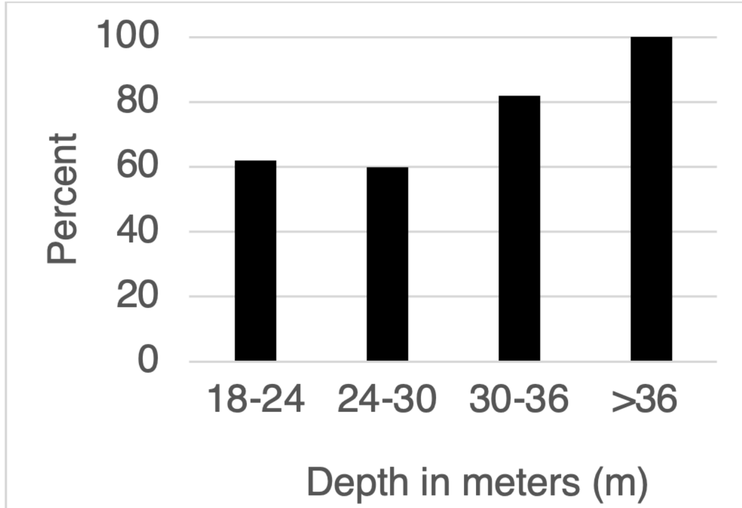

Figure 2. Percentage of Red Grouper (*Epinephelus morio*) caught on hook-and-line in the commercial fishery that were unvented and unable to return to the capture depth (N = 222 fish). X-axis = depth in meters. Y-axis = percent of red grouper unable to return to the capture depth (N = 222 fish). X-axis = depth in meters. Y-axis = percent of red grouper unable to descend. *Original graph by* [8][8]. *Koenig et al., this paper, converted the x-axis from feet to meters and labeled the axes.*

The primary question addressed in this document is: To what extent does the commercial fishery in the SEUS contribute to goliath grouper bycatch mortality? To answer this question, we use bycatch data collected by NOAA Fisheries and the known impacts of capture and release at various depths provided in the published literature.

Materials and Methods

Data. --We used data from NOAA Fisheries discard logbooks recorded by commercial fishers in the SEUS to estimate their contribution to the decline of the adult goliath grouper populations noted by [5] and [6]. Because the NOAA bycatch data account for only 10% of the commercial fishery, according to the NOAA contact providing the data, we assumed that multiplying these data by ten would more closely represent the entire commercial bycatch of goliath grouper.

Analyses. --We used XLSTAT 2023.2.1414 Statistical Software for Excel by [10]1 (Lumivero, Inc. Denver, CO) to analyze the data. Analyses included: (1) a linear regression of the overall goliath grouper commercial catch data to determine the total number of fish captured by the fishery annually and any possible trends in the data; (2) a linear regression of the depth of capture to determine if the depths of capture change over time; and (3) a literature search for capture-release mortality data that could provide a framework for estimating depth-of-capture mortality for goliath grouper. This last point is important because while [9] explored the impacts of depth of capture on goliath grouper, we relied on [11] for a mathematical framework.

An appropriate statistical regression model for bivariate dependent variables (survival or death) is logit (or probit). That is, a logistical regression evaluates the relationship between depth of capture and mortality. Depth of capture is analogous to ‘dose’ in the medical literature. The deeper the depth of capture, the larger the ‘dose’ effect on the fish, resulting in mortality due to expansion and rupturing of the swim bladder. However, there are other capture-related factors that contribute to death, including predation on weakened released fish, lethal hooking damage to the gills and other vulnerable organs, improper venting of the swim bladder, absence of venting, length of time on deck, and treatment by fishers. Most capture-release studies are short term, such as studies conducted in cages[12], and do not include all the potentially lethal factors.

To determine relevant factors involved in the mortality of goliath grouper based on capture depth and treatment by commercial fishers required that we find prior studies on either goliath grouper or other groupers to provide the framework. The only study on goliath grouper capture-release

doi.org/10.32388/RWEF3Z.2

barotrauma is that of [9]. She documented reasonable survival potential for goliath grouper caught at moderate depths and vented prior to release, noting that, "*The most extreme cases of barotrauma for Goliath Groupers occurred at sites deeper than 30 m. These fish exhibited stomach eversion, intestinal protrusion from the anus and gas bladder expansion... Extreme cases required lengthy and multiple venting procedures before fish were able to descend independently.*"

Figure 3, copied from Collins's dissertation[9], shows degrees of barotrauma for goliath grouper caught in water depths of 10 to 38 m. Severity of barotrauma and conditions resulting from barotrauma were significantly higher at depths greater than 30 m. Figure 4, also from [9], shows that neither the size (total length, TL) nor the total period monitored had any significant bearing on the severity of barotrauma.

One study that encompasses potential sources of mortality in groupers is the long-term capture-release study conducted by [11] on gag grouper (*Mycteroperca microlepis*). In that study, volunteers in the commercial fisheries of North Carolina, South Carolina, Georgia, and Florida captured, tagged, vented, and released 3,876 gag groupers from 1995 to 1999, a period of 5 years, using diverse types of hooks. Many of the tagged groupers were at liberty for years, some moving distances as great as 185 km. In the absence of a similar comprehensive long-term study on goliath grouper, or on any other grouper, we used this study to estimate depth-of-capture-related mortality (i.e., mortality from barotrauma). We applied the resulting regression equation of gag mortality from [11] (Figure 5) to goliath grouper capture data from [9] to estimate capture-release barotrauma mortality.

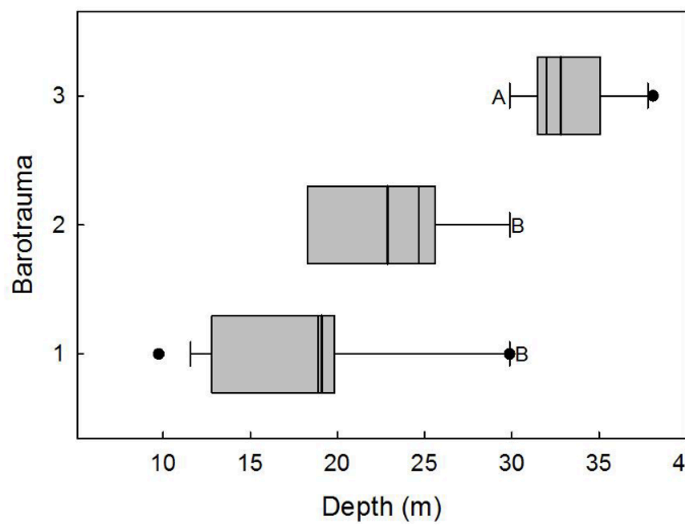

Figure 3. Relative degrees of barotrauma in the western Atlantic Goliath Grouper *(Epinephelus itajara)* in the Southeastern United States resulting from depths of capture. X-axis = depth in meters. Y-axis = relative severity of trauma, classed as (1) minimal, (2) moderate, and (3) severe. Bold lines within the whisker plot are means, and thin lines are medians. Severe barotrauma results when caught in depths greater than 30 m. Designations A and B indicate significant statistical difference among plots. Graph from[9].

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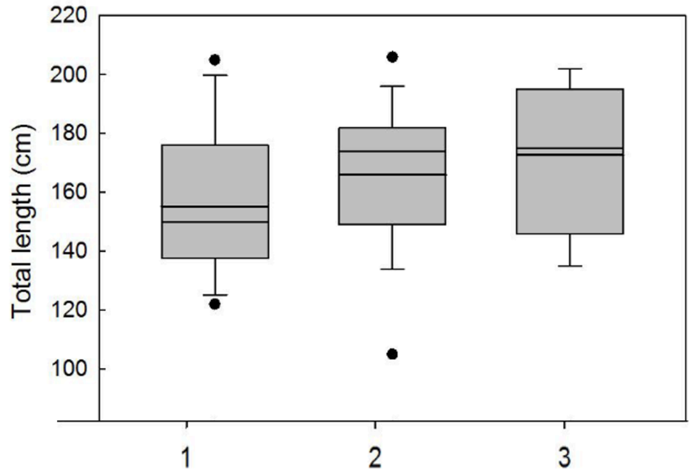

Figure 4. Relative degrees of barotrauma of the western Atlantic Goliath Grouper (*Epinephelus itajara)* in the Southeastern United States based on standard lengths (TL, cm), wherein barotrauma levels evaluated were: (1) minimal, (2) moderate, (3) severe. Mean and median are indicated by the bold and thin horizontal lines, respectively. Whiskers = 95% confidence limits; • = observations outside the 95% confidence interval. There was no relationship between TL and barotrauma groups (p=0.536). *Graph from Collins, A.*[9]

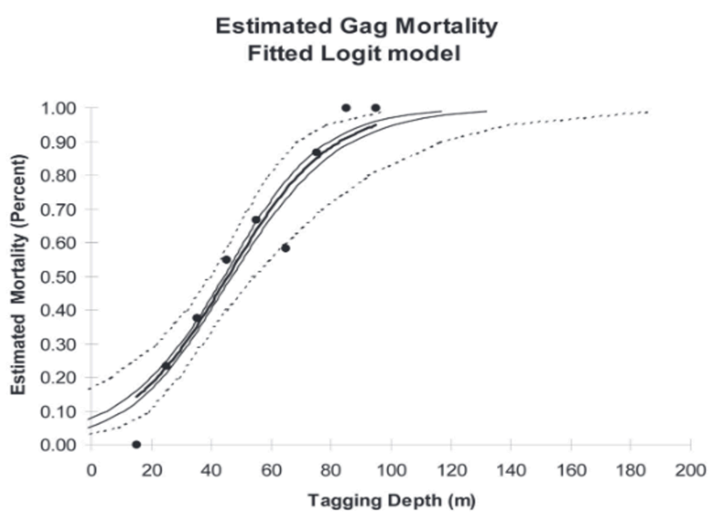

Figure 5. Logit regression of percent mortality of Gag (*Mycteroperca microlepis*) relative to depth-of-capture. Estimated mortality (thick line), 95% confidence limits (thin line), and 99% confidence limits (dashed lines). Regression equation: P = 1 / (1 + EXP(–(-2.6773 + 0.0588*X1))). *Graph from*[11]*, used here with permission of the J. McGovern.*

Results

We took the total number of goliath groupers recorded as bycatch in NOAA logbooks between 2002 and 2022, which represented 10% of the commercial fishery, and multiplied it by 10 to estimate the catch for the entire fishery. We estimated that the commercial fishery captured 18,770 goliath groupers during that period, of which 12,860 (69%) had depth-of-capture reported and 5,910 (31%) did not.

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There was no significant trend in capture data over time (Figure 6) and a significant increasing trend (*P < 0.001*) in depth of capture over the time series (Figure 7). Among the total caught, only 480 fish were recorded as having died on landing. The condition of others was unclear, given such notations in the logbooks as "most alive" or "most dead." Table 1 shows the number of goliath grouper caught as bycatch in commercial fisheries between 2002 and 2022 where depth data were available, as well as their distribution among depth intervals and the relative associated barotrauma mortality, based on the equation that[11] used for gag grouper. For the 5,910 additional individuals for which no capture-depth data existed, we assumed that all of them occurred across depth intervals in the same proportions as the fish for which depth data were available (Table 2), leading us to calculate their barotrauma mortality with that in mind, again following[11].

Of the total number of goliath grouper caught (18,770 = $12{,}860_{\text{depth data present}} + 5{,}910_{\text{depth data absent}}$), we estimate that 7,601 (= $4{,}879_{\text{depth data present}} + 2{,}242_{\text{depth data absent}} + 480_{\text{reported dead}}$) died from barotrauma. That amounts to 40% mortality due to barotrauma alone in the commercial fishery.

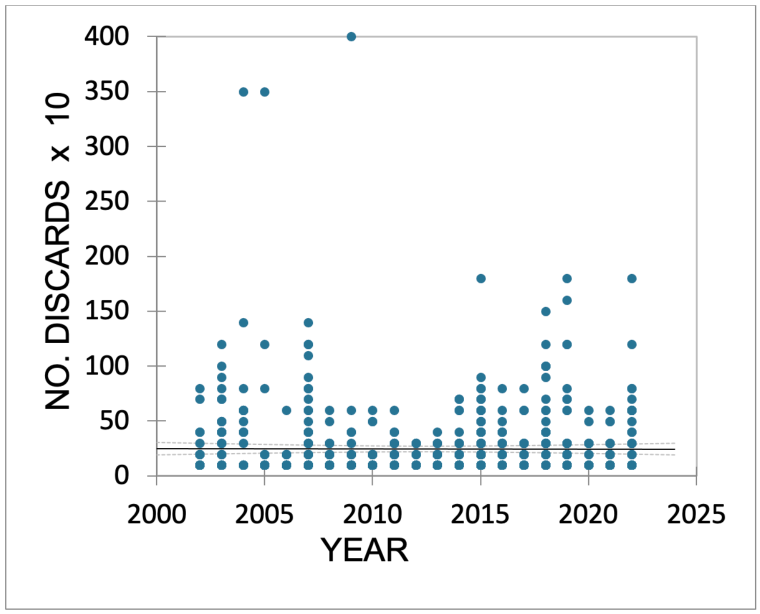

Figure 6. Linear regression of western Atlantic Goliath Grouper *Epinephelus itajara* discarded as bycatch from 2002 to 2022 in commercial fisheries of the Southeastern United States. Solid line = slope. Dashed lines = 95% confidence limits (CL) of the mean. Regression equation: Number of Discards x 10 = 58.55 -.0168 * YEAR. N = 18,770.

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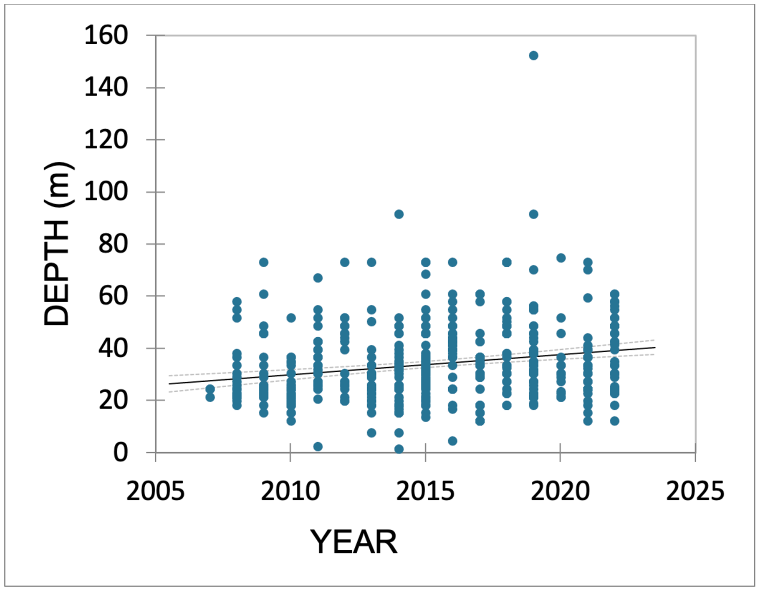

Figure 7. Linear regression of capture depth of western Atlantic Goliath Grouper (*Epinephelus itajara*) bycatch in commercial fisheries of the Southeastern United States. Solid line = mean depth of capture. Dashed lines = 95% confidence limits (CL) of the mean. Regression equation: DEPTH (m) = -1534.8 + 0.78 * YEAR; R^2 = 0.046. The slope of the regression line is significantly positive ($p < 0.001$), meaning that the depth of capture increased over time. N = 12,860.

Figure 8. Image of a floating western Atlantic Goliath Grouper *Epinephelus itajara* after release from capture. *Photo from Stevely et al.*[8].

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Venting. -- If a recently captured bloated fish is not vented or returned to the bottom using a descending tool such as the ones described by[13] and[8], the

fish will float at the surface for an unknown period, likely resulting in its death by predation and/or damage to skin and eyes from sun exposure. The problem is that commercial fishers do not always record whether venting occurred or not. On commercial longline vessels, for instance, the sheer number of fish brought aboard at one time makes venting quite difficult and time-consuming.

Considering barotrauma alone, using the[11] model for gag—we found that 38% of the goliath grouper caught in the commercial fishery would have experienced release mortality. In the absence of venting, however, significantly more goliath grouper would have died from hemorrhage, organ damage, and the inability to descend to the bottom (Figure 8).

We used 30 m depth of capture as a minimum depth for venting goliath grouper based on[9]. We then calculated the number of fish caught in the commercial fishery between 2002 and 2022 at depths of 30 m or greater, and the number caught at depths less than 30 m. We assumed that no venting occurred in the 12,319 goliath grouper caught deeper than 30 m and thus all fish died. We also assumed that all 6,451 goliath grouper caught in less than 30 m experienced barotrauma, and that 1,325 of them died, based on[11] equation. Thus, total release mortality was 75% (Table 3). Given that around 683 goliath groupers die each year on average, then a total of 13,664 mortalities occurred over the period 2002 to 2022.

Median depth (m)	Depth interval (m)	Mortality Probability	Number caught	Number died
95	90-100	0.9482	30	28
85	80-90	0.9106	0	0.0
75	70-80	0.8497	410	348
65	60-70	0.7585	350	265
55	50-60	0.6357	910	578
45	40-50	0.4922	2750	1354
35	30-40	0.3500	3990	1397
25	20-30	0.2302	3210	739
15	10-20	0.1424	1150	164
5	0-10	0.0844	60	5
		Totals	12,860	4,879

Table 1. Estimates of barotrauma mortality of western Atlantic Goliath Grouper *Epinephelus itajara* bycatch in commercial fisheries of the Southeastern United States between 2002 and 2022 where depth data were available, based on probabilities derived from the logistic regression equation P = 1 / (1 + EXP(-(-2.6773 + 0.0588*X1))) used to estimate capture-depth mortality for Gag *Mycteroperca microlepis* by[11]. Probabilities are for median depths; reported captures are from the depth intervals.

doi.org/10.32388/RWEF3Z.2

Median Depths (m)	Number reported depths	Proportion at depth	Number with unreported depths	Number died (unreported depths)
95	30	0.0023	14	13
85	0	0.0000	0	0
75	410	0.0319	188	160
65	350	0.0272	161	122
55	910	0.0708	418	266
45	2750	0.2138	1264	622
35	3990	0.3103	1834	642
25	3210	0.2496	1475	340
15	1150	0.0894	528	75
5	60	0.0047	28	2
Totals	12860	1.0	5910	2242

Table 2. Estimates of barotrauma mortality of western Atlantic Goliath Grouper *Epinephelus itajara* bycatch by the Southeastern United States commercial fisheries between 2002 and 2022 that lacked depth data. Probabilities derived from logistic regression equation P = 1 / (1 + EXP(-(-2.6773 + 0.0588*X1))) used to estimate capture-depth-related mortality of Gag *Mycteroperca microlepis* by[11]. Probabilities are calculated for median depths; captures are from the depth interval.

Depth information	Number caught	Numerical mortality	Percent mortality
Without depth data	5,910	Barotrauma: 2,242	Barotrauma: 38%
With depth data	12,860	Barotrauma: 4,879	Barotrauma: 38%
≥ 30 m	12,319	Non-venting: 12,319	Non-venting: 100%
< 30 m	6,451	Barotrauma: 1,325	Barotrauma: 21%
Total Morality		Non-venting ≥ 30m + Barotrauma < 30m + reported = 480: 12,319 + 1,325 + 480 = 14,124	Non-venting + Barotrauma 75%

Table 3. Summary of catch and mortality (numerical and percent) data from non-venting and barotrauma in the commercial catch of thewestern Atlantic Goliath Grouper *Epinephelus itajara* in the Southeastern United States.Total fish caught = 18,770; total reported dead = 480.

Discussion

It is clear from the foregoing data analyses of goliath grouper bycatch in the SEUS commercial fishery that incidental capture negatively affects its population. That does not mean that charter and recreational fisheries are blame-free. They are not. Recreational fishers contribute to population decline through a targeted catch-and-release fishery focused on goliath grouper spawning aggregations (depths 20 – 32 m), and by poaching[5]. The management decision made by the commissioners of the Florida Fish and Wildlife Conservation Commission that allows a targeted harvest of juvenile goliath grouper after a 32-year moratorium adds to that effect[5].

[14] point to the necessity of monitoring bycatch of endangered, threatened, and protected species. They indicate that fishers often consider interactions with protected species to be controversial and therefore will neither record nor report them.[15], for instance, found large disparities in Australian

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fisheries discard data based on two sources of discard information across all the fisheries and methods they described, with logbook data of fishers representing only 10% of that recorded by observers—an under-reporting rate of 90%. A similar bias likely occurs for goliath grouper because fishers know it is protected.

Analyses of the data in this report show that the commercial fishery of the SEUS produces a constant negative effect on the recovery of the protected goliath grouper population of the US. The full impact is unclear, given that NOAA Fisheries only collects about 10% of the self-reported discard data, the accuracy of which is dubious at best. The estimates presented in this report show a significant impact of capture in commercial fisheries. However, these data still underestimate bycatch because the commercial fishers tend to underreport bycatch while overreporting the survival of goliath grouper, given that it is a species protected in federal waters.

Because capture-release recreational fisheries are common off Florida, observer or camera-based monitoring should extend to these fisheries as well, especially since[8] showed with red grouper that capture depths as shallow as 18 m could inhibit descent to the bottom where these fish live. Bycatch of goliath grouper in other sectors of the recreational fishery also has a negative influence on the population and suggests that NOAA Fisheries should train both recreational *and* commercial fishers in the proper handling and venting of goliath grouper.

Further, fishers need to be aware of the damage to fish caught on J-hooks compared to Circle-hooks, with J-hooks responsible for higher mortalities[8]. Factors responsible for increasing release mortality are hook location, depth of capture, and extended handling times. Our work with goliath grouper[16][17] demonstrated that critical factors leading to goliath grouper fishing mortality included improper (or lack of) venting, imbedded hooks and leader from prior capture events, imbedded hook location, hook type, and handling times.

We show that depths of capture of goliath grouper in commercial fisheries have increased over time, which means that barotrauma mortality will certainly increase with it. Even if fishers routinely vent fish, goliath grouper are severely damaged by hemorrhage and organ damage as they reach the surface from deepwater captures. Further, the bias of self-reporting in charter and commercial fisheries is well known. For that reason alone, it is imperative that the scientific data collected are accurate and that they lead to rule-making that halts the damage occurring to this protected species. If the true bycatch of goliath grouper is to be known, then both charter and commercial vessels need to have paid observers onboard as well as remote electronic monitors.

Conclusions

In this paper, we show that the commercial fishery of the Southeastern United States (SEUS) has a significant detrimental effect on the recovery and survival of goliath grouper captured as bycatch, particularly for fish captured at depths $\geq$ 30 m. We note that the depth of capture has increased over time (Figure 7), suggesting that the rate of lethal barotrauma has increased.

About 10% of the commercial fishers in the SEUS self-report bycatch of goliath grouper. Given the tendency for this sector universally to bias catch and bycatch reports toward lower capture and a higher survival rate (e.g., [18]), it is imperative that NOAA and the Florida Fish and Wildlife Conservation Commission stop using logbooks[19] and go beyond the current pilot studies of remote electronic monitoring in the grouper fishery of the SEUS (https://www.fisheries.noaa.gov/national/fisheries-observers/electronic-monitoring, accessed 3 December 2023) to full implementation. That would ensure more effective, prompt, and reliable data on commercial discards and bycatch of this and other protected species, thereby strengthening their protection.

Statements and Declarations

Acknowledgments

We thank NOAA Fisheries for supplying the commercial fisheries logbook data for this study. The authors of this paper received no external funding to support the research.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflicts of interest.

Animal Use in Research

We used no animals in the conduct of this research.

Author Contributions

Conceptualization, original draft, methods, formal analysis - C Koenig; validation - C Koenig, F Coleman; writing, editing – C Koenig, F Coleman; formatting, map – F Coleman; review – J. Locascio. All authors have read and agreed to the published version of the manuscript.

Footnotes

[1] Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

Data Availability Statement

The Goliath Grouper bycatch data analyzed in this study were obtained from the National Oceanic and Atmospheric Administration (NOAA) Fisheries logbook program covering the period 2002–2022. These data are subject to confidentiality restrictions and are not publicly available. Derived data supporting the conclusions of this article (e.g., aggregated summaries, model parameters) may be made available by the authors upon reasonable request, pending any restrictions from the original data provider. Inquiries can be directed to the corresponding author.

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Declarations

Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.