Research Article

Estimates of Atlantic Goliath Grouper (Epinephelus Itajara) Bycatch Mortality in Commercial Fisheries of the Southeastern Us From 2002 to 2022

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Atlantic Goliath Grouper *Epinephelus itajara* is experiencing a population decline in the southeastern United States currently due to a combination of factors, including increasingly large and persistent red tides, loss of juvenile habitat, severe cold-weather events, and bycatch, the unintended capture by commercial and recreational fishers. In this paper, we review the extent of bycatch in the southeastern United States from 2002 to 2022 resulting from commercial fishing only based on data from NOAA Fisheries logbooks. We calculated depth-of-capture-related mortality based on known patterns of depth-related barotrauma and assumed that all captures deeper than 30 m that were unvented prior to release died based on observations of other researchers. The overall result is that 75% (14,124 of 18,770) *Epinephelus itajara* captures died from both barotrauma and from inability of the fish to return to the bottom due to trapped swim bladder gas.

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1. Introduction

Commercial 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, depth of capture and whether the bycatch can descend to the bottom independently. Forced ascents of fish cause gas expansion and possible bursting of the closed 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 Atlantic Goliath Grouper (*Epinephelus itajara,*) the largest reef fish in the Atlantic Ocean, reaching lengths of 2.5 m (Heemstra and Randall 1993). *E. itajara* approached extinction in the southeastern United States (SEUS) by the late 1980s, leading the National Oceanic and Atmospheric Administration (NOAA) and in the State of Florida to protect them by 1990. Both overfishing and the loss of mangroves, the primary juvenile habitat, contributed to this decline (Koenig et al. 2020). 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 (Craig 2011), to "vulnerable" in 2018. This change resulted from a modification in data interpretation rather than a change in population status (Bertoncini *et al.* 2018).

The *E. itajara* population is now suffering yet another decline (Coleman et al. 2023, Locascio et al. 2023). Contributing factors include red tides, continued loss of essential juvenile habitat, severe cold-weather events which are lethal to tropical species like *E. itajara*, snook (*Centropomis undecimalis*) (Coleman *et al.* 2023) and bycatch by commercial and recreational fisheries. Add to this a directed fishery for juveniles that opened in Florida in March 2022 (Coleman *et al.* 2023), and bycatch mortality becomes a significant issue.

Estimating capture-release mortality across fishing gears and times is difficult because of the range of factors that contribute to this mortality. We have already mentioned hook-induced mortality, 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 in which a syringe or trocar-cannula is inserted through the body wall into the swim bladder, releasing the gas confined therein, and allowing the fish to descend to the bottom

 doi.org/10.32388/RWEF3Z

(Drumhiller *et al.* 2014). Unvented fish typically float on the surface after release if captured at depths greater than about 30 m (Collins 2014). If the fish float for extended periods of time, they experience damage to their eyes and skin from the sun and are highly vulnerable to predation.

The primary question addressed in this document is: To what extent does the commercial fishery in the SEUS contribute to *E. itajara* 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.

2. Materials and Methods

2.1. Data

The data used in this study were from NOAA Fisheries discard logbook data recorded by commercial fishers in the SEUS. We used these data to estimate the contribution of the commercial fishery in the SEUS to the decline of the adult *Epinephelus itajara* population as expressed in papers by Locascio *et al.* 2023 and Coleman *et al.* 2023. Because the NOAA bycatch data represent only 10% of the commercial fishery, according to the NOAA contact who provided the data we assume that multiplying these data by ten would represent the entire commercial bycatch of *E. itajara*.

2.2. Analyses

We used XLSTAT 2023.2.1414 (Lumivera 2023) to analyze the data. Analyses included: (1) a linear regression of the overall *E. itajara* 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 *E. itajara*. This last objective is important because only Collins (2014) explored the impacts of depth of capture on *E. itajara*.

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 because of the 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 (Burns et al. 2002), and do not include all the potentially lethal factors.

2.3. Relevant literature

To determine relevant factors involved in the mortality of *E. itajara* relative to capture depth and treatment by commercial fishers required that we find prior studies on either *E. itajara* or other groupers to provide the framework. The only study on *E. itajara* capture-release barotrauma is that of Collins (Collins 2014). She documented reasonable survival potential for *E. itajara* caught at moderate depths and vented prior to release, stating 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 1, copied from Collins’s dissertation (Collins 2014), shows degrees of barotrauma for *E. itajara* caught in water depths of 10 to 38 m. Severity of barotrauma and conditions resulting from barotrauma were significantly higher in depths greater than 30 m, whereas Figure 2, also from Collins (2014), showed that size of captured *E. itajara* had no significant effect on the severity of barotrauma.

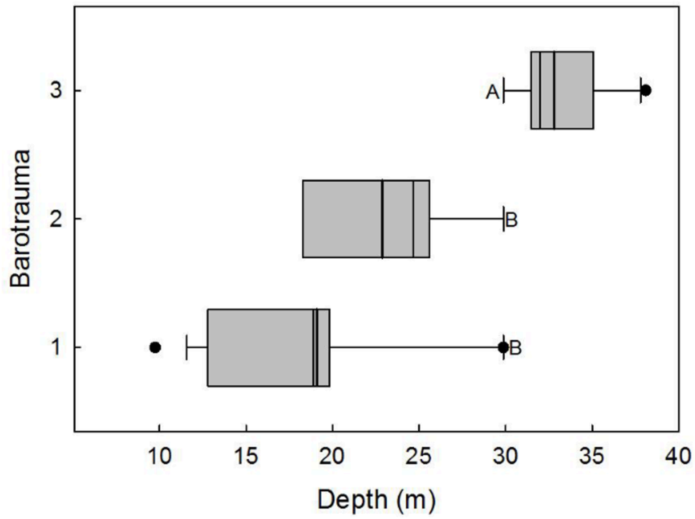

Figure 1. Relative degrees of barotrauma in the Atlantic Goliath Grouper (*Epinephelus itajara)* in the Southeastern United States resulting from depths of capture. X-axis = depth in meters. Y-axis = relative severity of trauma, classed as (1) minimal, (2) moderate, and (3) severe. Bold lines within the whisker plot are means and thin lines are medians. Severe barotrauma results in *E. itajara* caught in depths greater than 30 m. *Graph from Collins, A. (Collins 2014).*

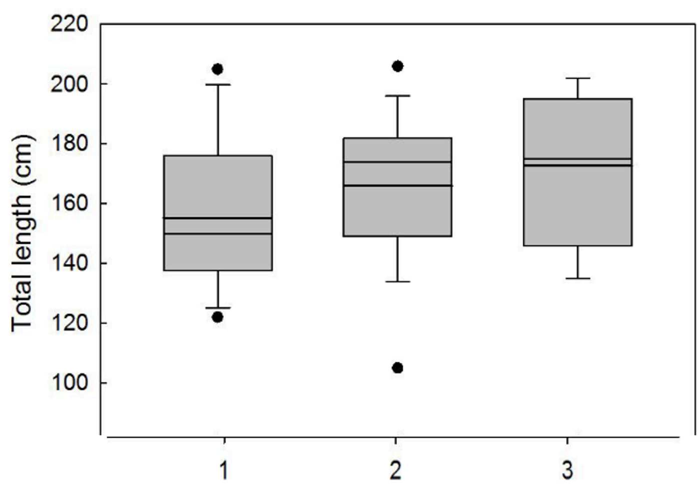

Figure 2. Relative degrees of barotrauma of the Atlantic Goliath Grouper (*Epinephelus itajara)* in the Southeastern United States based on standard lengths (TL in cm), wherein barotrauma levels evaluated were: (1) minimal, (2) moderate, and (3) severe. Mean and median are indicated by the bold and thin horizontal lines, respectively. Whiskers = 95% confidence limits; • = observations outside of the 95% confidence interval. There was no relationship between total length and barotrauma groups (p=0.536). *Graph from Collins, A. (Collins 2014).*

One study that encompasses potential sources of mortality in groupers is the long-term capture-release study conducted on Gag (*Mycteroperca microlepis*) by McGovern *et al.* (McGovern et al. 2005). In that study, 3,876 Gag were captured, tagged, vented, and released by volunteers in the commercial fisheries of North Carolina, South Carolina, Georgia and Florida from 1995 to 1999. In the absence of a similar

doi.org/10.32388/RWEF3Z

comprehensive long-term study on *E. itajara*, or on any other grouper, we used this study to estimate depth-of-capture-related mortality (i.e., mortality from barotrauma) because the tagging effort took place over 5 years by members of the commercial fishery, different types of hooks were used, and many of the tagged groupers were at liberty for years.

We applied the resulting regression equation on *M. microlepis* mortality from McGovern et al. (2005) (Figure 3) to *E. itajara* capture data to estimate capture-release barotrauma mortality.

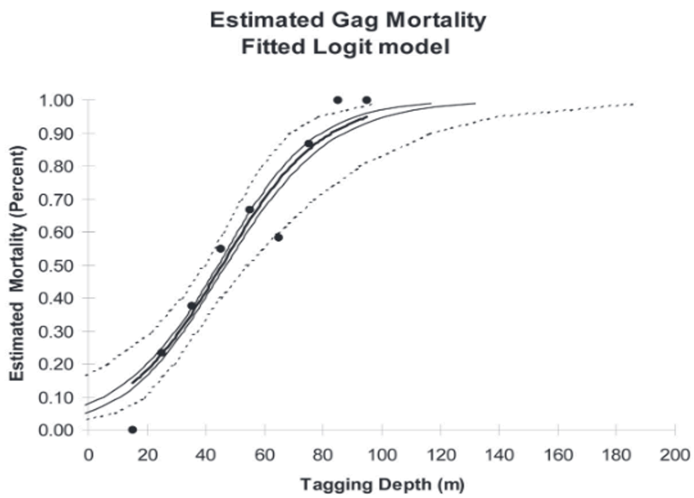

Figure 3. Logit regression of percent mortality of Gag (*Mycteroperca microlepis*) relative to depth-of-capture. Estimated mortality (thick line), 95% confidence limits (thin line) and 99% confidence limits (dashed lines). Regression equation: P = 1 / (1 + EXP(-(-2.6773 + 0.0588*X1))). *Graph from McGovern et al. (2005).*

Stevely et al. (Stevely et al. 2014) conducted a study on fish descent after capture by hook-and-line, primarily focusing on Red Grouper (*Epinephelus morio*) which demonstrated that 60% of the fish captured could not descend in water depths as shallow as 18 m (Figure 4). This may have been the case for *E. itajara* as well, but Collins (2014) did not determine the minimum depth that the fish could descend, only the minimum depth at which barotrauma was severe. Thus, the minimum capture depth in which floating was not a problem for *E. itajara* is an overestimate; that is, they undoubtedly had descent issues at depths less than 30 m.

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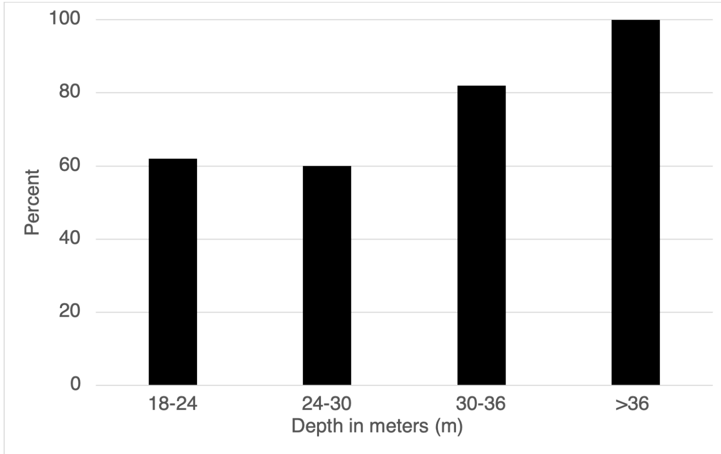

Figure 4. Percentage of Red Grouper (*Epinephelus morio*) caught on hook-and-line in the commercial fishery that were unvented and unable to return to the capture depth (N = 222 fish). X-axis = depth in meters. Y-axis = percent of red grouper unable to descend. *Original graph by Stevely et al. 2014 (Stevely et al. 2014). Koenig et al., this paper, converted the x-axis from feet to meters and labeled the axes.*

3. Results

3.1. Barotrauma

In the NOAA Fisheries data, the total adjusted number of *Epinephelus itajara* (multiplied by 10 to estimate catch for the entire fishery) captured by the commercial fishery from 2002 to 2022 was 18,770: 12,860 with depth of capture reported and 5,910 without depth of capture reported. There was no significant trend in capture data over time (Figure 5) and a significant increasing trend ($p < 0.001$) in depth of capture over the same time series (Figure 6). Among the total caught, 480 were reported dead on landing. The condition of others was unclear given such notations in the data files as “most alive” or “most dead.”

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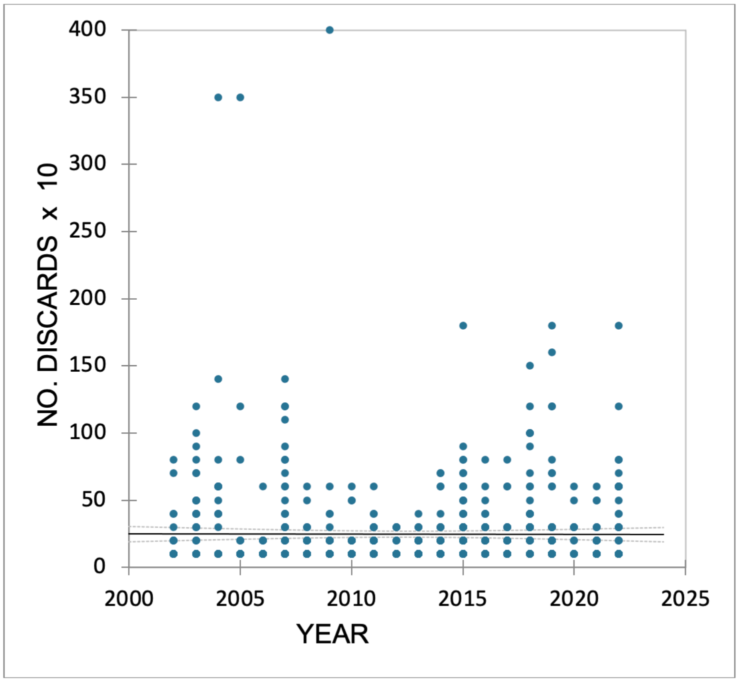

Figure 5. Linear regression of Atlantic Goliath Grouper *Epinephelus itajara* discarded as bycatch from 2002 to 2022 in commercial fisheries of the Southeastern United States. Solid line = slope. Dashed lines = 95% confidence limits (CL) of the mean. Regression equation: Number of Discards x 10 = 58.55 -.0168 * YEAR. N = 18,770.

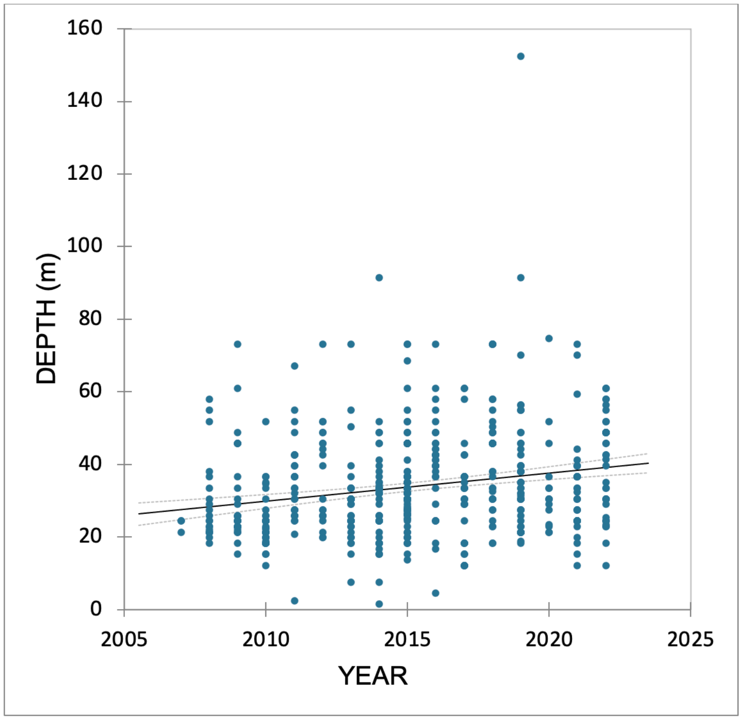

Figure 6. Linear regression of capture depth of Atlantic Goliath Grouper (*Epinephelus itajara*) bycatch in commercial fisheries of the Southeastern United States. Solid line = mean depth of capture. Dashed lines = 95% confidence limits (CL) of the mean. Regression equation: DEPTH (m) = -1534.8 + 0.78 * 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.

Table 1 shows the number of *E. itajara* caught as bycatch in commercial fisheries between 2002 and 2022 (N = 12,860 with depth data), as well as their distribution among depth intervals and the relative associated barotrauma mortality, based on the equation that McGovern *et al.* (2005) used for *M. microlepis.*

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Median depth (m)	Depth interval (m)	Probability of mortality	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 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 logistic regression equation P = 1 / (1 + EXP(-(-2.6773 + 0.0588*X1))) used to estimate capture-depth mortality for Gag *Mycteroperca microlepis* byMcGovern et al. (2005). Probabilities are for median depths; reported captures are from the depth intervals.

There were 5,910 additional individuals for which there were no capture-depth data (Table 2). We assumed that these fish occurred across depth intervals in the same proportions as the fish *with* depth data, leading us to calculate their barotrauma mortality with that in mind, again following McGovern et al. (2005).

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 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 McGovern et al. (2005). Probabilities are calculated for median depths; captures are from the depth interval.

Of the total number of *E. itajara* 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.

3.2. Venting

If a recently captured bloated fish is not vented or returned to the bottom with some type of descending tool such as the ones described by Runde and Buckel (Runde and Buckel 2018) and Stevely et al. (Stevely et al. 2014), the fish will float at the surface for an unknown period of time (see Figure 7), likely resulting in its death by predation and/or damage to skin and eyes from sun exposure. The problem is that the commercial catch data do not indicate whether venting occurred at all. On commercial longline vessels, for instance, the sheer number of fish brought aboard at one time makes venting quite difficult. Collins (Collins 2014), for instance, stated that it took considerable effort to vent fish caught at depths greater than 30 m. Thus, we must consider the lack of venting and improper venting as likely causes of mortality additional to barotrauma, as described above.

Figure 7. Image of a floating Atlantic Goliath Grouper. *Epinephelus itajara* after release from capture. *Photo from Stevely et al. (Stevely et al. 2014).*

Considering barotrauma alone, using the McGovern *et al.* (2005) model for Gag—we found that 40% of the *E. itajara* caught in the commercial fishery would have experienced release mortality. In the absence of venting, however, significantly more *E. itajara* would have died from hemorrhage, organ damage, and the inability to descend to the bottom.

We used 30 m depth of capture as a minimum depth for venting *E. itajara* based on Collins's observations (Collins 2014). 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 *E. itajara* caught deeper than 30 m and thus all fish died. We also assumed that all 6,451 *E. itajara* caught in less than 30 m experienced barotrauma, and that 1,325 of them died, based on McGovern's et al. equation (2005). Thus, total release mortality was 75% (Table 3). Given that around 683 *E. itajara* die each year on average, then a total of 13,664 mortalities occurred over the period 2002 to 2022.

doi.org/10.32388/RWEF3Z

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 + dead 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 the Atlantic Goliath Grouper *Epinephelus itajara* in the Southeastern United States.Total fish caught = 18,770; total reported dead = 480.

4. Discussion

It is clear from the foregoing data analyses of *Epinephelus itajara* bycatch in the SEUS commercial fishery that there is a substantial negative effect of this type of capture on the *E. itajara* population. That does not mean that recreational fishing has no impact. It does, through a targeted catch-and-release fishery focused on *E. itajara* spawning aggregations (depths 20 – 32 m), and by poaching (Coleman et al. 2023). The recent management decisions allowing a harvest of juvenile *E. itajara* after a 32-year moratorium adds to that effect (Coleman et al. 2023).

Gray & Kennelly (2018) report on the necessity of monitoring bycatch of endangered, threatened, and protected species. They point out that fishers consider interactions with protected species to be controversial and therefore often do not record or report these events (Gray & Kennelly 2018). Kennelly (2020), for instance, observed that bycatch data in Australian fisheries show large disparities between the two sources of discard information across all the fisheries and methods they described. Logbook data provided estimates that were just 10% of that estimated from the observer data—that is an under-reporting rate of 90%; the same biased reporting likely occurs for *E. itajara*. If the true bycatch of *E. itajara* is to be known, commercial vessels need to have paid observers or remote electronic monitors operating onboard.

Analyses of the data in this report demonstrate that the commercial fishery of the SEUS produces a constant negative effect on recovery of the protected *E. itajara* 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 significant impact of capture in commercial fisheries. However, these data still represent an underestimate because the commercial fishers tend to underreport bycatch and overreport survival of *E. itajara,* 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 Stevely et al. (Stevely et al. 2014) showed (with Red Grouper *E. morio*) that capture depths as shallow as 18 m could inhibit descent to the bottom where these fish reside. Bycatch of *E. itajara* 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 proper handling and venting of *E. itajara* caught as bycatch.

They also need to be aware of the relative damage to fishes caught on J-hooks relative to Circle-hooks, with J-hooks responsible for higher mortalities (Stevely et al. 2014). Factors responsible for increasing release mortality are hook location, depth of capture, and extended handling times. From our work with *E. itajara* -- Koenig & Coleman (2009, 2016), we found that venting, imbedded hooks and leader from prior capture events, imbedded hook location, hook type and handling times were critical factors contributing to *E. itajara* mortality.

We show that depths of capture of *E. itajara* in commercial fisheries have increased over time, which means that barotrauma mortality will certainly increase with it. Even if fishers routinely vent fish, *E. itajara* are severely damaged by hemorrhage and organ damage as they reach the surface from deepwater captures. For that reason alone, it is imperative that scientific data collected are accurate and that they lead to rule-making that halts the damage occurring to this protected species.

5. 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 *Epinephelus itajara* captured as bycatch, particularly for fish captured at depths ≥ 30 m. We note that depth-of-capture has increased over time (Figure 6), indicating that the rate of lethal barotrauma has increased and shows no sign of abating.

About 10% of the commercial fishers in the SEUS self-report bycatch of *E. itajara*. Given the tendency for this sector universally to bias catch and bycatch reports toward lower capture and a higher survival rate (e.g., Brown et al. 2021), it imperative that NOAA and the Florida Fish and Wildlife Conservation Commission 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 December 3, 2023) to full implementation. That would ensure more effective, timely, and reliable data on commercial discards and bycatch of this and other protected species, thereby strengthening their protection.

Statements and Declarations

Acknowledgments

We thank Stephen Smith, NOAA Fisheries, for providing 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.

Author Contributions

Conceptualization, C Koenig; methodology, C Koenig; validation, C Koenig, F Coleman; formal analysis, C. Koenig; investigation C. Koenig, F Coleman, J. Locascio; writing—original draft preparation, C Koenig; writing, editing – C Koenig, F Coleman; review – J. Locascio. All authors have read and agreed to the published version of the manuscript.

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Declarations

Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.