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B. J. Runde[1] , P. J. Rudershausen [2,*], and G. R. Stilson[3]

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Management Brief

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B. J. Runde[1], P. J. Rudershausen[2,*], and G. R. Stilson[3]

[1]The Nature Conservancy, Charlottesville, Virginia, USA
[2]Center for Marine Sciences and Technology, Department of Applied Ecology, North Carolina State University, Morehead City, North Carolina, USA
[3]North Carolina Department of Environmental Quality, Division of Marine Fisheries, Morehead City, North Carolina, USA

*Corresponding author: P. J. Rudershausen. Email: pjruders@ncsu.edu.

ABSTRACT

Objective: Our objective was to use annual data on recreational fishing effort and the number of large Dolphinfish *Coryphaena hippurus* caught in North Carolina to determine if their abundance has changed over recent decades.

Methods: We gathered data on citation-sized Dolphinfish (≥15.9 kg) and Wahoo *Acanthocybium solandri* (≥18.1 kg) from the North Carolina Division of Marine Fisheries and fishing effort data from the National Marine Fisheries Services's Marine Recreational Information Program. We generated species-specific annual values for trips per citation caught. Linear models were fit to these data by regressing them against year.

Results: An analysis of covariance model with a separate regression slope for each species provided the best fit to the data for trips per citation caught. Our data set from 2000 to 2023 revealed a meaningful and roughly fourfold increase in the effort required to catch a citation-sized Dolphinfish, while no trend was observed for Wahoo.

Conclusions: A substantial increase in effort required to catch a citation-sized Dolphinfish suggests that the abundance of large individuals of this species has declined. In the context of no such trend for Wahoo, possible confounding causes (e.g., changing social norms) are unlikely to explain our finding. Causes of the decline for Dolphinfish are likely related to increased exploitation of the stock.

KEYWORDS: Dolphinfish, population dynamics, recreational data, Wahoo, western North Atlantic

LAY SUMMARY

Our study suggests declining stock health of Dolphinfish, a species of great economic importance in the western North Atlantic. A dramatic decline in the abundance of the largest individuals in a stock may reflect overexploitation. Our results are informative for U.S. federal fishery managers who are considering updated size and bag limits for Dolphinfish in the region.

INTRODUCTION

A common objective of recreational anglers is to catch extremely large individuals of targeted species (Fedler & Ditton, 1994; García-Asorey et al., 2011; Magee et al., 2018). As fisheries develop, larger individuals are often most susceptible to removal (Berkeley al., 2004; Coble, 1988; Hilborn & Walters, 2013; Huntsman et al., 1999). Marine recreational fisheries in general can have substantial effects on fish stocks (Lewin et al., 2006; Shertzer et al., 2019). Indeed, the health of a fish stock may be indexed by time-series data on the level of effort required to capture an individual of exceptionally large size (Goodyear, 2015).

Dolphinfish *Coryphaena hippurus* are a pelagic predator that are found in tropical and subtropical waters worldwide (Moltó et al., 2022). In the western North Atlantic (WNA), the Dolphinfish contributes to valuable recreational fisheries (Lynch et al., 2018; Merten et al., 2014). Although there are no long-term fishery-independent surveys that attempt to index the Dolphinfish stock in the WNA, recent studies have indicated possible overexploitation of the species (Damiano et al.,

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2024; Lynch et al., 2018). Additionally, a recent study predicted declines in the median total length of male Dolphinfish by 168 and 105 mm from 2003 to 2023 and 2007 to 2023, respectively, for two sportfishing tournaments in North Carolina. Female Dolphinfish showed even greater declines in these tournaments, with reductions of 354 and 199 mm in total length over the same periods (Rudershausen et al., 2024). Researchers have called for regionwide precautionary Dolphinfish management in light of the increased fishing pressure and uncertainty regarding stock health (Merten et al., 2022; South Atlantic Fishery Management Council [SAFMC], 2021).

The North Carolina Division of Marine Fisheries (NCDMF) administers The North Carolina Saltwater Fishing Tournament (Citation Program) in which they recognize recreational landings of exceptionally large sizes of popular sport fish (NCDMF, 2024). Any angler, except those who sell their fish or work on a for-hire vessel, may participate in this program if their catch meets a minimum species-specific cutoff weight at the scale of an official North Carolina weigh station. Recognition of a citation (i.e., large) fish consists of a physical certificate with the details of the angler's catch included. Annual data on the number of species-specific citations have been kept by the NCDMF since 2000.

The amount of angler effort influences catch of individuals of certain sizes. Scaling catch data by effort (i.e., calculating catch per unit effort or effort per unit catch) is one means of reducing variability in catch data and revealing temporal trends in size-based catches (Hubert & Fabrizio, 2007). The U.S. National Marine Fisheries Service measures bimonthly and annual saltwater recreational fishing effort through its Marine Recreational Information Program (MRIP) Fishing Effort Survey (MRIP, 2024). This recreational effort survey canvases angler participation at regional and state geographic scales. This program underwent a transition between 2015 and 2018 from a telephone survey to a mail survey; although these methods (and their questions) are not identical, they were conducted simultaneously during the four transition years to allow comparison and calibration. Data from the MRIP can be used as an estimate of annual effort that can scale the number of citation-sized fish that are entered into the NCDMF Citation Program.

In this study, we examined the number of recreational fishing trips (from the MRIP) taken per citation-sized Dolphinfish weighed by North Carolina recreational anglers from 2000 to 2023. We tested the null hypothesis that the amount of effort that is required to catch a citation-sized Dolphinfish, and therefore the availability of large Dolphinfish, has not changed through the study period. This research provides timely information to fishery managers who are seeking to address potential recent declines in size and abundance of this recreationally important species in the WNA.

METHODS

We used freely available NCDMF Dolphinfish citation data from 2000 to 2023 (A. Macek, NCDMF, personal communication). The minimum weight for a Dolphinfish citation is 15.9 kg and has remained the same across the 24-year study period. Our data set consisted of the catch date and total body wet weight of each fish that was entered into the citation program.

Table 1. Mean annual catch estimates (numbers of fish) for all Dolphinfish and Wahoo in North Carolina state waters (ocean inside three nautical miles) and in exclusive economic zone (EEZ) waters off North Carolina (3–200 nautical miles). Ratio state : EEZ is the ratio of catch in state waters to catch in EEZ waters. The data are from the National Marine Fisheries Services's Marine Recreational Information Program and consist of the arithmetic mean of total annual catch from 2000 to 2023.

	NC state waters	NC EEZ waters	Ratio state : EEZ
Dolphinfish	4,379	443,426	0.010
Wahoo	518	26,619	0.019

The number of citations that are given for a species in a single year may depend on factors other than the availability of large individuals of that species. For instance, social pressures (i.e., the popularity of the Citation Program, social media) or the availability of official weigh stations may have changed over time. We sought a means of controlling for factors (other than a decline of large Dolphinfish in the stock) that could influence the number of annual Dolphinfish citations in the North Carolina program. Thus, in addition to obtaining citation data for Dolphinfish, we obtained North Carolina citation data for Wahoo *Acanthocybium solandri* from 2000 to 2023 (minimum weight 18.1 kg; constant through the study period). The Wahoo is an apex pelagic predator fish that occupies a niche similar to that of Dolphinfish off North Carolina (SAFMC, 2003). Because Wahoo and Dolphinfish cohabitate, are susceptible to the same terminal tackle, and are commonly caught during similar times of year and often on the same recreational trips, we used Wahoo as a reference species in this study. A temporal trend showing changing numbers of citations for one of these species but a lack of a trend in the other would indicate that the species with increasing effort per catch for citation-sized individuals is experiencing these changes due to changes in the size structure of the stock rather than changing angler participation in the Citation Program.

We obtained estimates of effort (angler trips) from the online MRIP query tool (MRIP, 2024). Our query parameters of MRIP effort were "annual estimates for calendar year," "North Carolina only," "all fishing modes combined," and "federal exclusive economic zone only." We restricted our analysis of effort data to federal waters off North Carolina only because at these latitudes in the USA, Atlantic Dolphinfish and Wahoo are almost exclusively caught more than three nautical miles from shore (Table 1; MRIP, 2024). We modeled MRIP angler trips per citation fish (Table 2) as a function of year and fish species using linear models (Table 3). The full analysis of covariance (ANCOVA) model for this study had the formula

$$Trip \sim year + species + year \times species,$$

where *trips* is the number of trips per citation $trips = E / C = 1/(qN)$, where E is effort, C is catch, q is catchability and assumed constant, and N is abundance. *Year* × *species* is a two-way interaction term between these two variables (i.e., separate slopes model). We compared the output of this separate slopes ANCOVA model with a reduced model without an interaction term (i.e., a shared-slopes model) and a model excluding *species* entirely (shared slope and shared intercept

Table 2. Catch (annual citations issued), effort (annual recreational angler trips), and effort per catch for citation-sized Dolphinfish and Wahoo in North Carolina. The recreational angler trip estimates are from the National Marine Fisheries Services's Marine Recreational Information Program for waters of the exclusive economic zone off North Carolina. The lower and upper 95% values represent confidence interval bounds for angler trips (from the Marine Recreational Information Program), and effort per catch lower and upper 95% bounds are calculated using these boundary values for effort.

Year	Dolphinfish citations	Wahoo citations	Angler trips	Angler trips lower 95%	Angler trips upper 95%	Trips per Dolphinfish	Trips per Dolphinfish lower 95%	Trips per Dolphinfish upper 95%	Trips per Wahoo	Trips per Wahoo lower 95%	Trips per Wahoo upper 95%
2000	318	717	589,372	496,958	681,785	1,853	1,563	2,144	822	693	951
2001	459	516	513,874	441,356	586,391	1,120	962	1,278	996	855	1,136
2002	408	539	570,859	444,425	697,293	1,399	1,089	1,709	1,059	825	1,294
2003	410	449	545,526	461,057	629,996	1,331	1,125	1,537	1,215	1,027	1,403
2004	117	805	695,661	562,039	829,284	5,946	4,804	7,088	864	698	1,030
2005	170	671	815,922	675,191	956,652	4,800	3,972	5,627	1,216	1,006	1,426
2006	197	599	785,147	660,497	909,797	3,986	3,353	4,618	1,311	1,103	1,519
2007	219	501	933,863	787,433	1,080,292	4,264	3,596	4,933	1,864	1,572	2,156
2008	426	325	570,927	467,978	673,877	1,340	1,099	1,582	1,757	1,440	2,073
2009	173	363	702,043	556,187	847,900	4,058	3,215	4,901	1,934	1,532	2,336
2010	158	422	520,899	412,677	629,122	3,297	2,612	3,982	1,234	978	1,491
2011	119	397	539,339	418,829	659,849	4,532	3,520	5,545	1,359	1,055	1,662
2012	102	641	541,007	455,117	626,898	5,304	4,462	6,146	844	710	978
2013	219	769	493,754	377,623	609,886	2,255	1,724	2,785	642	491	793
2014	211	543	515,644	393,354	637,934	2,444	1,864	3,023	950	724	1,175
2015	139	575	718,591	546,762	890,421	5,170	3,934	6,406	1,250	951	1,549
2016	92	638	704,963	543,301	866,625	7,663	5,905	9,420	1,105	852	1,358
2017	105	953	622,132	455,077	789,187	5,925	4,334	7,516	653	478	828
2018	122	509	556,467	428,858	684,076	4,561	3,515	5,607	1,093	843	1,344
2019	180	739	526,686	403,841	649,530	2,926	2,244	3,609	713	546	879
2020	93	533	684,256	516,613	851,899	7,358	5,555	9,160	1,284	969	1,598
2021	68	336	507,380	390,033	624,726	7,461	5,736	9,187	1,510	1,161	1,859
2022	61	462	367,507	274,587	460,428	6,025	4,501	7,548	795	594	997
2023	53	386	514,178	392,235	636,120	9,701	7,401	12,002	1,332	1,016	1,648

Table 3. Bayesian information criterion (BIC) scores for the four linear regression models fit in this study. The full model is an ANCOVA examining the differential trend in the annual amount of recreational fishing effort per citation-sized Dolphinfish or Wahoo weighed by the North Carolina Division of Marine Fisheries from 2000 to 2023.

Model	BIC	ΔBIC	Weight
Trip ~ year + species + year × species	834.6	0.0	1
Trip ~ year + species	849.0	14.4	0
Trip ~ year	884.3	49.7	0
Trip ~ 1 (intercept only)	886.2	51.6	0

model, i.e., simple regression). Additionally, we fitted a null (intercept-only) model. For each fit model, we assumed that *trips* was a normally distributed random variable. The preferred model was selected by comparing Bayesian information criterion (BIC) scores, which are most appropriate for hypothesis testing (Aho et al., 2014). Modeling was conducted using R (R Core Team, 2023).

After identifying the most likely model, we sought to test for autocorrelation. We first examined a scatterplot of residuals of fit values versus year for the best-fitting model. A pattern to the plot would indicate autocorrelation. Second, we conducted a Durbin–Watson test on the model output (Durbin & Watson, 1971). The Durbin–Watson test statistic and P-value were examined for significance ($P < 0.05$). This procedure was conducted using the R package "lmtest" (Zeileis & Hothorn, 2002).

We observed a trend in Dolphinfish citation data that could plausibly have been explained by changing migration timing of that species (see Results). Therefore, we investigated whether there has been an annual trend in the timing of citations received for Dolphinfish. We fit a generalized linear model to yearly data on ordinal day of Dolphinfish citations (i.e., *day ~ year*) and a separate generalized linear model where year was omitted (i.e., intercept only model; *day ~ 1*). The model comparison proceeded as above.

RESULTS

The NCDMF awarded 4,619 Dolphinfish citations from 2000 to 2023, with a high of 459 in 2001 and a low of 53 in 2023. Within that same period, they awarded 13,388 Wahoo citations, with a high of 953 in 2017 and a low of 325 in 2008. The MRIP-estimated number of angler trips to federal waters off North Carolina averaged roughly 600,000 per year from 2000 to 2023, and uncertainty in these estimates was generally around 10% annually (Table 2). Calculations of trips per citation showed a substantial increase in effort per citation for Dolphinfish, with the last year in the time series exceeding the first year by a factor of >5, but no trend was observed for Wahoo (Figure 1).

In modeling effort per citation data, the most likely model explaining trends in per citation-sized Dolphinfish included an interaction between *species* and *year* (Table 3). None of the other models that we examined received any support in the BIC

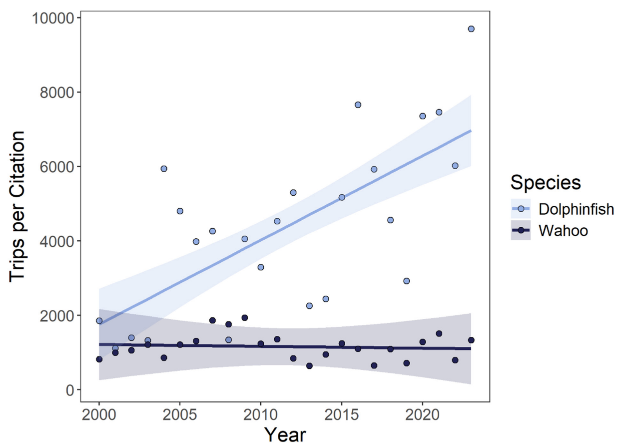

Figure 1. Amount of fishing effort (number of recreational trips to the exclusive economic zone off North Carolina, USA, per citation-sized Dolphinfish [light blue] or Wahoo [dark blue]) weighed by the North Carolina division of marine fisheries. Point data for trips per citation (y-axis) are presented annually (x-axis) along with estimated trendlines and 95% confidence regions (shaded areas). Adjusted multiple R^2 for this model was 71.34%.

comparison. The adjusted multiple R^2 for the most likely model was 71.34%. We found no evidence of autocorrelation, as the residual plot showed no pattern and the Durbin–Watson test was nonsignificant (DW = 1.78; P = 0.11). The inclusion of the interaction term in the most likely model and species-specific predictions (Figure 1) showed increasing effort required to catch a citation-sized Dolphinfish relative that required to catch a citation-sized Wahoo (Table 4). With each successive year, 232 additional trips were necessary to catch a citation-sized Dolphinfish relative to the number of trips to catch a citation-sized Wahoo. The modeled number of trips per citation for Dolphinfish showed roughly a fourfold increase from the beginning of the time series to the end. Thus, we rejected the null hypothesis that there has been no temporal trend in the amount of effort required to catch a citation-sized Dolphinfish.

Our model of ordinal day of Dolphinfish citations by year indicated that citations are caught slightly earlier now than at the beginning of the time series (Figure 2). The modeled average annual decrease in ordinal day was 0.16 d, meaning that across 24 years, there has been a decrease in average capture date of approximately 3.8 d. The model BIC was 45,382.8, with a selection weight of 0.89, whereas the intercept-only model received some support in comparison (BIC = 45,387.0; weight 0.11).

DISCUSSION

We found a substantial increase in the number of fishing trips that was required to catch an exceptionally large Dolphinfish off North Carolina over the first quarter of this century. Our model predictions indicate that a nearly fourfold increase in effort is required to catch (and land) a Dolphinfish at least 15.9 kg over the 24-year study period. Within the context of no temporal trend in the modeled results for another offshore pelagic predatory fish, the Wahoo, this trend for Dolphinfish is cause for concern regarding the health of the population and abundance of the spawning stock in the WNA.

It is possible that factors other than changing availability of large Dolphinfish could have influenced our results. For instance, there have been several changes to recreational Dolphinfish measures in this region since 2000, beginning with the inception of the Dolphin-Wahoo Fishery Management Plan in 2003 (Table S1 [see online Supplementary material]; SAFMC, 2003). However, these measures were generally incremental and a 2022 reduction in bag limit (from 60 fish to 54 fish per vessel) was estimated to decrease recreational landings by less than 1% (SAFMC, 2021); because the temporal trend we observed began well before this change, we do not believe that changing measures could be responsible for it. Furthermore, the availability of citation-sized Wahoo might have increased substantially, coupled with a decrease in the propensity of anglers to obtain citations for qualifying catches. However, we maintain that the most likely explanation is a decline in large Dolphinfish and explain below.

There are several environmental and anthropogenic effects that may have affected our results on increasing effort per citation for Dolphinfish over the first quarter of this century. Climate-induced range shifts in marine fish species in this region are occurring (Cao et al., 2024; Morley et al., 2018) and could have influenced the availability of large Dolphinfish. However, we believe that range shifts are unlikely to explain the trend in Dolphinfish citations, as Damiano et al. (2024) found no evidence for a shifting range of Dolphinfish in this region and in fact showed a decline in abundance in the Mid-Atlantic region (adjacent and northward of North Carolina) in the most recent years of their time series. The authors speculated that fishing activity and/or environmental effects (i.e., climate) may be to blame for this decline. Dolphinfish move northward along the U.S. East Coast in the spring (Merten et al., 2014), so changing migration timing may have resulted in the decreased availability of large Dolphinfish. However, our analysis of Dolphinfish citation timing suggested only very minor changes, with less than a 4-day shift from 2000 to 2023 (Figure 2). We therefore do not believe that changes in migration timing could have caused the overall trend we observed.

Increasing catchability due to changing gear efficiency may have changed during the study period. However, neither technique nor terminal tackle in this fishery have changed markedly over the past two decades (Rudershausen et al., 2012). Conversely, fishing technology, including the quality of outboard motors and on-board electronics (e.g., omni-directional SONAR and navigation systems), have advanced substantially during the study period. If these advancements have influenced the catch of large pelagic fish, we assume that the directionality of that influence would be toward greater efficiency of catching large pelagic fish, not lesser. Thus, the increasing effort required to produce a citation-sized Dolphinfish may be conservatively estimated in this study.

One source of uncertainty in our analysis is that our choice of data for estimating effort may not accurately reflect effort for pelagic species, including Dolphinfish and Wahoo. We conducted a follow-up modeling analysis whereby we restricted effort data to the for-hire fishing fleet only (all other MRIP data query parameters remained the same, i.e., 2000–2023, annual effort, NC only, EEZ only). Linear modeling proceeded as described in the Methods whereby we used for-hire trips per citation as the response variable in the ANCOVA model.

Table 4. Model output from an ANCOVA examining the differential trend in the annual amount of recreational fishing effort per citation-sized Dolphinfish or Wahoo weighed by the North Carolina Division of Marine Fisheries from 2000 to 2023.

Term	Description	Estimate	SE	*t*	*P*
Intercept	*y*-intercept for linear regression model relating Dolphinfish trips per citation to year	−451,341.35	73,141.55	−6.17	<0.0001
Year	Slope of linear regression model relating Dolphinfish trips per citation to year	226.55	36.35	6.23	<0.0001
SpeciesWahoo	*y*-intercept for linear regression model relating Wahoo trips per citation to year	462,505.75	103,409.49	4.47	<0.0001
Year × SpeciesWahoo	Relative distance between linear regression models relating Dolphinfish and Wahoo trips per citation to year	−231.52	51.41	−4.50	<0.0001

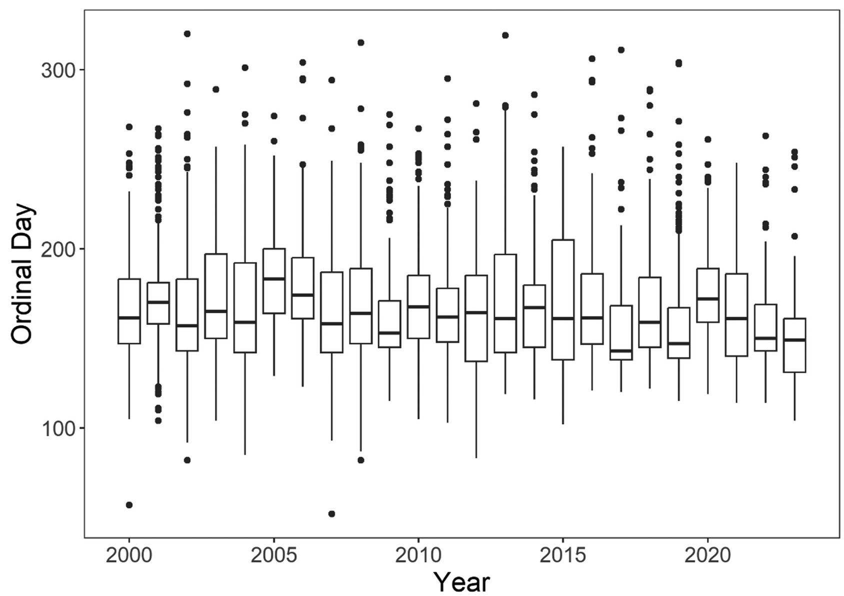

Figure 2. Box and whisker plots of annual ordinal day of capture (*y*-axis) of Dolphinfish awarded citations by the North Carolina Division of Marine Fisheries annually from 2000 to 2023 (*x*-axis). For each plot, the median value is represented by the horizontal black line within each box; the interquartile range (IQR) is represented by the vertical size of each box, 1.5 × the IQR is represented by the whiskers, and outlying observations are represented by filled points.

Using this response variable, we found nearly identical results; an approximate fourfold increase in effort was required to produce a citation-sized Dolphinfish, but there was no discernible trend for Wahoo. Another source of uncertainty with the MRIP estimates of fishing effort is that the proportion of angler trips to federal waters that have targeted pelagic predators, including Dolphinfish and Wahoo, may have changed during our study period. However, our side-by-side analysis of two co-occurring pelagic species controls for any such change.

In addition to studying temporal changes in the amount of effort required to produce a citation-sized Dolphinfish, we also conducted a post hoc investigation into whether annual median weights of citation entries has changed. Via simple linear regression (i.e., median weight ~ year), we found no change in median weights over time. This makes sense given that the North Carolina Citation Program has a minimum size criterion for entry of a Dolphinfish. Thus, our sample of studied Dolphinfish sizes is not representative of those in the greater WNA population but, instead, of the relatively few large fish that anglers choose to enter in the Citation Program. When investigating potential temporal changes to median sizes, the declining numbers of citation-sized Dolphinfish in recent years are offset by the entry of a few exceptionally large individuals (fish ≥ ~25 kg). This positively affects the relatively small sample sizes comprising each annual size distribution and is statistically expressed as having a relatively large effect on each annual median over recent years (Figure 3).

Our results are consistent with those of recent research that modeled fishery-dependent data and suggested that Dolphinfish may be currently overexploited in the WNA region (Rudershausen et al., 2024). Their study and ours used largely independent data and response metrics, yet both reports indicate overexploitation. Moreover, when combined with multiple findings of declining commercial and recreational catches of Dolphinfish in this region (Damiano et al., 2024; Lynch et al., 2018), our findings indicate declining health of this stock. Maintaining the size (and therefore age) structure of a fish population is important when managing for sustainability, and the absence of large individuals can indicate declining health of a stock (Barnett et al., 2017; Goodyear, 2015). Indeed, reductions in the number of large individuals in a population can have substantial consequences for

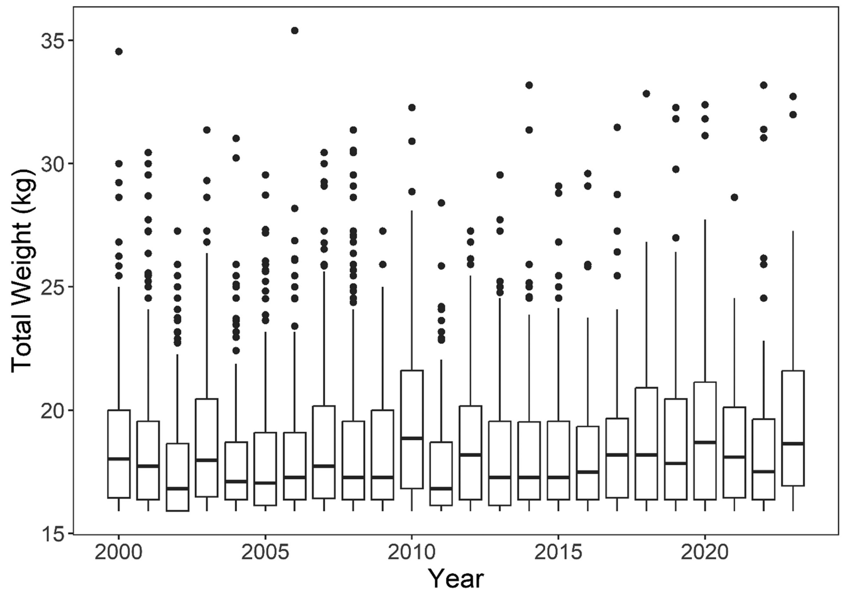

Figure 3. Box and whisker plots of annual total weights (y-axis) of Dolphinfish awarded citations by the North Carolina division of marine fisheries annually from 2000 to 2023 (x-axis). For each plot, the median value is represented by the horizontal black line within each box, the interquartile range (IQR) is represented by the vertical size of each box, 1.5 × the IQR is represented by the whiskers, and outlying observations are represented by filled points.

reproductive metrics like fecundity and recruitment (Barnett et al., 2017; Berkeley et al., 2004; Walsh et al., 2006), including for Dolphinfish (Chatterji & Ansari, 1982; Rudershausen et al., 2024). Our findings support the need for conservation measures for the WNA Dolphinfish stock, such as more stringent recreational bag limits, which the SAFMC is currently considering for the U.S. South Atlantic federal fisheries management region (SAFMC, 2023).

SUPPLEMENTARY MATERIAL

Supplementary material is available at *North American Journal of Fisheries Management* online.

DATA AVAILABILITY

The data underlying this article are available in the article and in the online Supplementary Material.

ETHICS STATEMENT

This research followed all American Fisheries Society, University, and national guidelines.

FUNDING

We have no funding sources to report.

CONFLICTS OF INTEREST

B. J. Runde holds the position of associate editor for *North American Journal of Fisheries Management* and has not peer reviewed or made any editorial decisions for this paper.

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