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ARTICLE

Retrospective Analyses of Commercial Trip Limit Efficacy in the Southeastern USA

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Abstract

Trip limits are frequently used as a management measure to control or reduce harvest by restricting harvest to a maximum amount. The goal of trip limits is often to lengthen the fishing season relative to the annual catch limit by slowing the landings rate or incentivizing fishers to target another species. Two recent commercial trip limits implemented in the southeastern USA were examined to determine the accuracy of the predicted changes in harvest. For South Atlantic Snowy Grouper *Hyporthodus niveatus*, analysts accurately predicted the change in landings (weight) that could be expected per trip in response to a trip limit increase but did not account for an increased number of trips early in the fishing season. An increased number of trips resulted in higher landings causing Snowy Grouper to reach the quota and close earlier than desired. For Gulf of Mexico Gray Triggerfish *Balistes capriscus*, analysts underestimated the predicted change in landings per trip that could be realized from implementing a trip limit (numbers of fish). The Gray Triggerfish analysis failed to account for fishers retaining larger individual fish on average after the trip limit was implemented, resulting in higher landings than predicted. When examining per-fish trip limits, it is recommended that other potential changes in fishing behavior, such as changes in the mean weight of fish being retained or increased effort, be considered. The results of this study could be used to improve the effectiveness of trip limits as a management tool.

With 63% of assessed stocks worldwide in need of rebuilding, it is vital to determine the effectiveness of different harvest control methods (Worm et al. 2009). Even within the USA, it is not clear what particular management actions have led to sustainable stocks for some species and overfished stocks for others (Cox et al. 2002; Melnychuk et al. 2013; Liu et al. 2016). The National Marine Fisheries Service (NMFS) is responsible for the stewardship of the nation's living marine resources in federal waters off the southeastern USA. The NMFS Southeast Regional Office works with three fishery management councils in the South Atlantic, Gulf of Mexico, and Caribbean to promote conservation and sustainability of a large number of valuable commercial and recreational species through direct (e.g., quotas, closures, trip limits, bag limits, size limits) and indirect (e.g., number of permits, restriction of vessel size) measures. The Magnuson–Stevens Fishery Conservation and Management Act reauthorization in 2006 required fishery management plans, as determined by the Secretary of Commerce, to establish a mechanism for specifying annual catch limits at a level that prevents overfishing and does not exceed the recommendations of the respective regional fishery management council's Scientific and Statistical Committee or other established peer review processes. By 2012, fishery management plans for all

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fisheries managed by the NMFS, except fisheries for species with annual life cycles or stocks subject to management under an international agreement, met the annual catch limit requirement (NMFS 2018).

Following the guidelines of the Magnuson–Stevens Act, if harvest for a species has met or is expected to meet the annual catch limit, one management response often used to control harvest is an in-season closure. In-season closures can result in negative public responses, and closed-harvest species are often discarded when fishermen target co-occurring species. Commercial at-sea discards are currently monitored through self-reported logbook data in the Gulf of Mexico and South Atlantic, in addition to a mandatory observer program on a subset of trips in the gulf (Scott-Denton et al. 2011; SEFSC 2018). Accurate discard estimates are vital since discards unaccounted for can result in a biased stock assessment, hindering the maintenance of a sustainable fishery (Punt et al. 2006), and limit an ecosystem approach to fishery management (Bellido et al. 2011; Condie et al. 2014). To reduce the chance of in-season closures, the fishery management councils often develop amendments to fishery management plans that include management measures (e.g., bag limits, trip limits, size limits) that are intended to keep landings below the annual catch limit. In an amendment to a fishery management plan, analyses are conducted to determine the effect the management measure will have on the future landings. Trip limits, which allow a vessel to retain catch up to a maximum amount on a trip, are often expected to lengthen the fishing season by slowing the landings rate or incentivizing fishers to target another species. The use of trip limits in the gulf and South Atlantic regions have become more common in recent years as fishery management councils have sought to reduce landing rates and the risk of a derby fishery for a number of species. An analysis of the impact trip limits have on landings is included in amendments to fishery management plans to inform fishery management councils and the public on the effects of its use as a management option.

The purpose of this paper is to retrospectively examine the accuracy of the analysis used in the amendments to the fishery management plans to predict changes from implementing trip limits. To reduce confounding factors, we focused on two species with few management changes (e.g., size limit, seasonal closures, or restrictive annual catch limit changes) and had a time period where the only change in the management of the stock was from a trip limit. We further restricted the scope by selecting trip limits that had been in place for multiple years after implementation when investigating the accuracy of the predictions. The two species that met the criteria are South Atlantic Snowy Grouper *Hyporthodus niveatus* and Gulf of Mexico Gray Triggerfish *Balistes capriscus*. Retrospective analyses were conducted to examine the actual change in landings versus the predicted change in landings for Snowy Grouper and Gray Triggerfish. This research aims to improve future trip limit analyses and possibly increase the effectiveness of trip limits as a tool for managers.

METHODS

Management history.— The final rule for Regulatory Amendment 20 to the fishery management plan for the Snapper–Grouper Fishery of the South Atlantic Region (Regulatory Amendment 20) increased the trip limit for Snowy Grouper from 45.4 kg (100 lb) gutted weight to 90.7 kg (200 lb) gutted weight (SAFMC 2014). The South Atlantic Fishery Management Council (South Atlantic Council) developed Regulatory Amendment 20 in response to an updated stock assessment in 2013 that showed that the stock was no longer experiencing overfishing and was rebuilding and that catch levels could be increased. The purpose of the trip limit increase was to allow for increased harvest, reduce regulatory discards when co-occurring species were being targeted, and minimize closures early in the fishing season when the annual catch limit was reached. Discards of Snowy Grouper can be detrimental to the health of the stock because they are a deepwater species (typically captured in > 100 m), and release mortality is estimated to be 100% (SEDAR 2013). It was assumed by the South Atlantic Council when they developed this regulation that additional trips (compared to historical levels) targeting Snowy Grouper would not occur after a trip limit was met.

In 2013, the final rule for Amendment 37 to the fishery management plan for the Reef Fish Resources of the Gulf of Mexico (Amendment 37) established a 12-fish trip limit for Gray Triggerfish (GMFMC 2012). The Gulf of Mexico Fishery Management Council (Gulf Council) developed Amendment 37 in response to an updated 2011 stock assessment that indicated that the stock was not rebuilding on target. The purpose of the trip limit was to aid in reducing the commercial catch and extend the length of the fishing season before an in-season closure occurred (GMFMC 2012). Given the small trip limit (only 12 fish), it was assumed by the Gulf Council when they developed this regulation that additional trips (compared to historical levels) targeting Gray Triggerfish would not occur after the trip limit was met.

General trip limit amendment analyses used in Regulatory Amendment 20 and Amendment 37.— General trip limit amendment analyses are frequently used in the Southeast region when predicting effects of potential changes. This general analysis applies to both species, in addition to details subsequently specified for each individual species. Two main data sets were used in predicting the effects from changing the trip limit in the amendment analyses. The total landings were retrieved from the

NMFS Southeast Fisheries Science Center (SEFSC) Accumulated Landings System, while trip-level information was obtained through the SEFSC Commercial Fisheries Logbook Program (CFLP). Accumulated Landings System landings are reported by seafood dealers to fisheries agencies in each state. The landings data reported by dealers do not contain specific information on fishers or vessels. Trip-level data were obtained from the CFLP data set. The CFLP collects detailed information, such as landings, gear used, area, and depth of capture, for each trip from all vessels holding federal permits to fish in federally managed waters.

To reflect any trends in landings for a species, an average of the most recent 2 to 5 years of data were usually used for predicting future trip limit changes during the development of an amendment. Predicted landings rates were used to project when the annual catch limit would be met under various trip limit scenarios being considered after regulations from an amendment were enacted. Impacts from new trip limits were calculated by altering trip catch in recent years to the newly proposed limit. For reductions or the creation of new trip limits, if total landings per logbook-reported trip were greater than the trip limit being analyzed, the value was reduced to the new trip limit, otherwise no changes to landed catch were made. The following formulas were used to estimate reductions in harvest from the trip limits:

$$\text{If landings} \leq \text{trip limit, then landings} = \text{landings}$$

$$\text{If landings} > \text{trip limit, then landings} = \text{trip limit.}$$

The monthly difference in landings between the status quo and the new trip limit was calculated to generate a monthly scalar. The scalar was then applied to the monthly dealer-reported landings to generate a harvest rate for predicting season length.

South Atlantic Snowy Grouper trip limit analysis in Regulatory Amendment 20.— In 2007, a trip limit for Snowy Grouper of 45.4 kg (100 lb) gutted weight was implemented primarily in response to an assessment that determined that the stock was overfished and undergoing overfishing (SAFMC 2006). The final rule for South Atlantic Regulatory Amendment 20 increased the trip limit from 45.4 kg (100 lb) gutted weight to 90.7 kg (200 lb) gutted weight based on a new assessment, which indicated that the stock was rebuilding and catch levels could be increased. Predictions for how increasing the Snowy Grouper trip limit would change landings assumed that all trips in the South Atlantic in 2012 and 2013 that met the trip limit would also meet the new trip limit (SAFMC 2014). This assumption provided a maximum estimated harvest rate that may occur when the trip limit is increased. While all trips meeting the previous trip limit would likely not meet the newly proposed trip limit, the information was not available to determine exactly how many additional kilograms of Snowy Grouper these trips would harvest once the trip limit was increased. South Atlantic trips from 2012 and 2013 that met the trip limit were defined as trips with landings of 40.8 kg or more (90% of the 45.4-kg limit). The range started at 40.8 kg instead of 45.4 kg to account for any trips that were close but slightly under the trip limit. Therefore, for the 90.7-kg trip limit, any trip that had between 40.8 kg to 90.7 kg landed was adjusted to be 90.7 kg. Trips that harvested below 40.8 kg were not modified. Trips with landings less than the proposed trip limit were not changed since these trips did not come close to the current trip limit in the past and would probably not come close to the new and higher trip limit in the future. Estimated changes were calculated for each month based on the difference in landings with the previous trip limit (45.4-kg trip limit) compared to landings when a trip limit was increased. The monthly scalars were applied to landings from 2012 and 2013 to predict future closure dates for Snowy Grouper. An average of the monthly scalars provided a predicted 62% increase in the landings from the increase in the trip limit.

Gulf of Mexico Gray Triggerfish trip limit analysis in Amendment 37.— In 2013, a 12-fish trip limit for the commercial sector was established for Gray Triggerfish through the final rule for Amendment 37 along with modifications to the annual catch limit and management measures for the recreational sector in an effort to end overfishing and rebuild the stock (GMFMC 2012). There had been no commercial trip limit in place prior to Amendment 37. Originally, a weight-based trip limit was considered for Gray Triggerfish in Amendment 37; however, based on the recommendations made by law enforcement, the Gulf Council decided to specify the trip limit in numbers of fish. Law enforcement felt it would be difficult to enforce a trip limit with such a low weight of Gray Triggerfish and enforcement would be enhanced if regulations specified an allowable number of fish per trip. The analyses first modeled the trip limit changes using weights and then converted the weights into numbers of fish.

Since the CFLP landings are in weight, the conversion to numbers of fish was done by dividing the landings weight by the mean weight of Gray Triggerfish. However, to account for the range of weights of Gray Triggerfish that could be harvested on a fixed number of fish per trip, a subsequent analysis was conducted to estimate the probability that a given number of Gray Triggerfish would exceed specified trip limits (e.g., probability that six fish exceeds an 11.3-kg trip limit). For this purpose, commercial landings data for Gulf Gray Triggerfish were obtained from the SEFSC Trip Interview Program. The Trip Interview Program data were collected by port samplers that interviewed commercial fishermen and collected

information on the length, weight, number of Gray Triggerfish landed, gear used, and trip identifiers (e.g., date, location). The analysis used data from 2009 through 2011.

A simulation was run (1,000 iterations), and for each iteration, a specified number of Gray Triggerfish (range = 3–25 fish) were randomly selected (with replacement) from the original Trip Interview Program data set. The total weight of each sample was calculated. The probability of exceeding the trip limits (by weight) was determined. The Gulf Council was comfortable with a 5–11% probability of exceeding the trip limit (in pounds). The analysis resulted in conversions of trip limit weight to numbers of fish of 11.3 kg to 6 fish, 22.7 kg to 12 fish, and 34 kg to 18 fish. The preferred trip limit selected by the Gulf Council in Amendment 37 was 12 fish per trip.

To model the trip limit alternatives in Amendment 37, the analysis modified CFLP trips greater than the trip limit to the new trip limit, otherwise no changes to landed catch were made. For example, a trip with 30 fish was reduced to the trip limit of 12 fish, and a trip with only 6 fish was not modified. Estimated reductions were calculated on a monthly basis based on the difference in landings with no trip limit compared with landings when a trip limit was imposed. The monthly scalars were applied to landings from 2009 through 2011 to predict future Gray Triggerfish closure dates. The 12-fish trip limit was predicted to decrease landings by 42%, independent of changes to other management measures that were being considered.

Retrospective analyses.—The retrospective analyses compared the actual landings after implementation of the new trip limits to the predicted landings from the analyses of Snowy Grouper and Gray Triggerfish in Regulatory Amendment 20 and Amendment 37, respectively. First, changes in effort and catch per unit effort (CPUE) using trip-level self-reported effort by gear were investigated as a metric to track differences due to the trip limits. However, exploratory analyses using effort or CPUE as an evaluation metric found them to be unacceptable due to diverging evidence of a relationship between the trip limits and CPUE (Figures S.1–S.4 available separately online in the Supplement). Difficulties also occurred when combining effort calculations from multiple gear types for comparison due to differences in reporting requirements for different gear. Additionally, overall effort has fluctuated across years. Snowy Grouper and Gray Triggerfish are often captured as bycatch and not specifically targeted; thus, attributing trip-level effort changes to limitations imposed on their harvest may not be possible. The decision to not use effort or CPUE as an evaluation metric is supported by earlier work by Richards (1994) that revealed little relationship between CPUE and landings when the trip limits imposed were at least moderately restrictive.

Landings per trip and per month as evaluation metrics were used to examine trip limit effects since both would likely be directly impacted by the management actions. We compared the values for landings per trip and per month against the expected outcomes of the trip limit analyses to gauge the success of managing with trip limits. For Snowy Grouper, the predicted changes were compared to the landings from 2016 through 2017. For Gray Triggerfish, the predicted changes were compared to the landings from 2014 through 2017.

RESULTS

The mean of the landings of Snowy Grouper per trip in the South Atlantic from 2013 through 2014 was 35.4 kg (Figure 1). After the trip limit was increased mid-2015, the mean landings of Snowy Grouper per trip increased 63% to 57.9 kg per trip from 2016 through 2017. The 63% increase in landings per trip coincides with the 62% increase in landings predicted by analysts when the amendment was developed. An examination of monthly landings for the same time period, however, revealed that average monthly landings more than doubled (Figure 2). Mean monthly landings for the first 5 months of the fishing season in 2016 and 2017 increased by between 114% and 168% compared with the mean from 2013 through 2014. Only January through May landings could be analyzed due to annual catch limit closures beginning in June during the years of interest. Further investigation found that the increase in monthly landings coincided with an increase in the number of trips that reported landing Snowy Grouper (Table 1). On average, 38% to 52% more trips per month were landing Snowy Grouper after the implementation of the trip limit increase than the 2 years prior, a sign of effort compression (increased number of fishing trips).

The mean of the landings of Gray Triggerfish per trip in the Gulf from 2009 through 2012 was 21.5 kg (Figure 3). After the 12-fish trip limit was implemented mid-2013, the mean landings of Gray Triggerfish per trip from 2014 through 2017 decreased 32% on average to 14.5 kg per trip. The 32% decrease in landings per trip is less than the 42% decrease in landings predicted by analysts. Monthly landings for the same time periods revealed a similar trend as the change in landings per trip with landings decreasing by 33% on average across all months after the trip limit was implemented (Table 2). Monthly changes in landings between the time periods varied from a 2% increase in February to a 43% decrease in November. The months of June and July were excluded due to a seasonal closure implemented at the same time as the trip limit in 2013. Additionally, landings after June in 2012 and November in 2017 were excluded due to annual catch limit closures.

An increase in the number of trips that reported landing Gray Triggerfish was not evident. Since the trip limit is in number of fish and not overall weight, it was

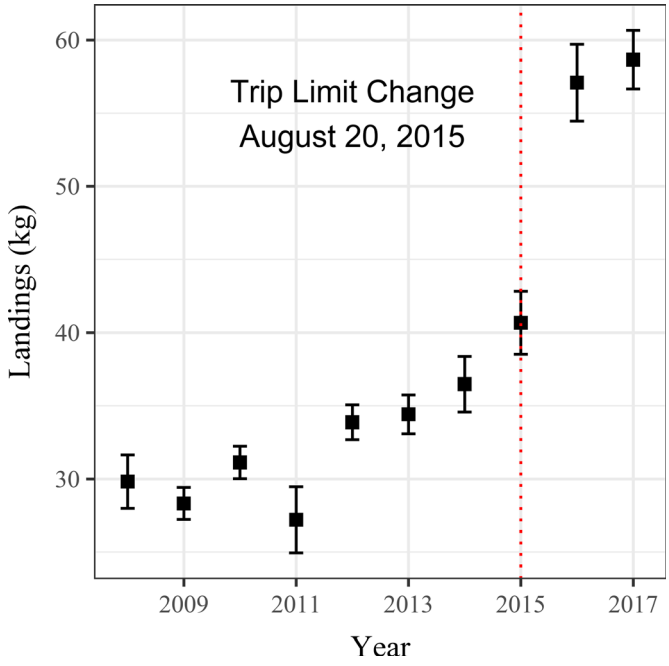

FIGURE 1. The mean landings (kilograms gutted; error bars show the 95% confidence intervals) of Snowy Grouper per trip in the South Atlantic from 2008 through 2017. The dashed red line shows when the trip limit change occurred.

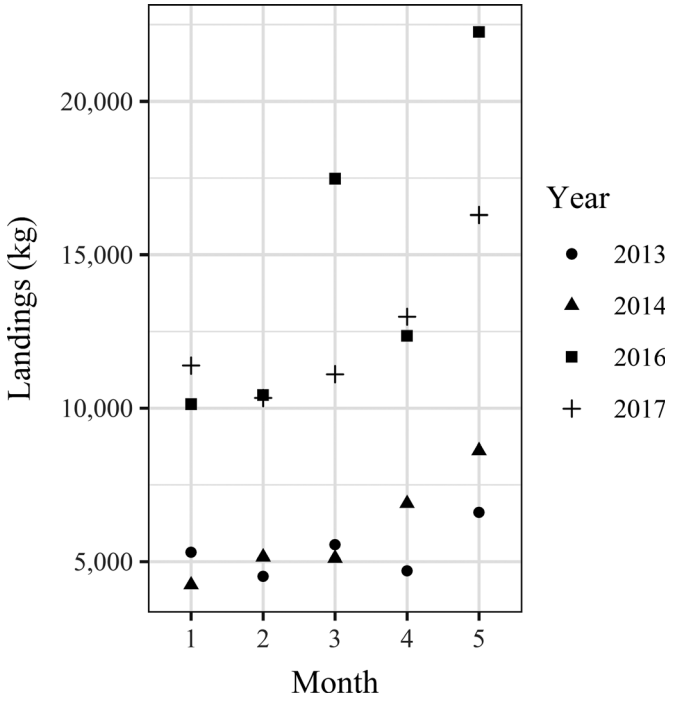

FIGURE 2. Monthly landings (kilograms whole) of Snowy Grouper in the South Atlantic from 2013 through 2017. Note that the landings after May were excluded due to quota closures and 2015 was removed since Regulatory Amendment 20 was implemented midyear.

theorized larger fish being landed could have accounted for the underestimate in predicted landings. Data from the Trip Interview Program were obtained from 2009 through 2017 and examined for differences in the mean weight of individual Gulf of Mexico Gray Triggerfish (Figures S.6). A general trend in increasing weight of individual Gray Triggerfish was evident beginning in 2014 (Figure 4). The mean whole weight of individual Gray Triggerfish landed from 2014 through 2017 of 1.91 kg was an 18% increase from the mean weight of 1.62 kg from 2009 through 2012. The underestimate for the predicted decrease in landings is likely due to the increase in mean weight of Gray Triggerfish being landed. "High-grading" could also have contributed to the increased mean weight. High-grading refers to selective harvesting by fishers for a species usually influenced by price differences based on fish size, i.e., increased discards of less valuable fish sizes. In this case, it was assumed the fishers could discard a smaller Gray Triggerfish to be able to retain a larger one.

DISCUSSION

To examine the impact that the trip limit had on landings, the analyses focused on South Atlantic Snowy Grouper and Gulf of Mexico Gray Triggerfish, which had few changes in commercial fishery management measures occurring after the trip limit was implemented. Trip limits are a common management measure used to regulate fisheries, but these tools only apply to retained catch; thus, the total effect on the stock may not be fully understood. Many of the species managed in the Gulf of Mexico and South Atlantic regions are captured together. Thus, species with a restrictive trip limit will often be discarded once the trip limit is reached when fishing for co-occurring species continues. For species with a high discard-mortality rate, an increase in fishing mortality may be realized from trip limits depending on the amount of discarding that occurs (Gillis et al. 1995). However, a more liberal trip limit can cause the annual catch limit to be reached more quickly, resulting in an in-season closure with the species being discarded when fishermen target co-occurring species. The trade-offs between harvest control methods and discards were modelled by Tetzlaff et al. (2013) for the Gulf of Mexico recreational fishery for Gag *Mycteroperca microlepis*, with an estimated discard mortality rate of 20%. Tetzlaff et al. (2013) found that the harvest control methods of size and bag limits resulted in a fishery at the edge of recruitment overfishing with low efficiency (high amounts of dead discards). A recent study by Runde et al. (2019) found discard mortality rates higher than 20% for Gray Triggerfish, and this high discard-mortality rate should be considered when management actions could potentially increase the number of discards.

TABLE 1. The number of trips landing Snowy Grouper in the South Atlantic per month from 2013 through 2017 and the total for each year for the first 5 months. Trips after May were excluded due to annual catch limit closures. The trip limit change occurred on August 20, 2015. The percent change is comparing the mean landings from 2013–2014 to 2016–2017.

Month and total	2013	2014	2015	2016	2017	Mean 2013–2014	Mean 2016–2017	% Change
Jan	136	99	167	178	176	117.5	177	51
Feb	110	115	130	154	164	112.5	159	41
Mar	123	128	212	218	163	125.5	190.5	52
Apr	98	137	163	158	167	117.5	162.5	38
May	163	206	186	295	213	184.5	254	38
Total	630	685	858	1,003	883			

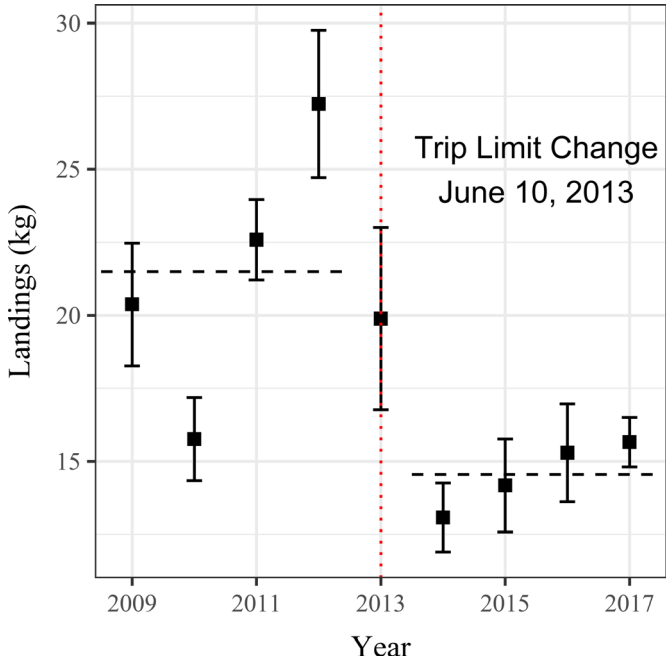

FIGURE 3. The mean landings (kilograms gutted; error bars show the 95% confidence intervals) of Gray Triggerfish per trip in the Gulf of Mexico from 2009 through 2017. The vertical dashed red line shows when the trip limit change occurred. The horizontal dashed lines represent the mean landings for each time period.

TABLE 2. Mean monthly landings (kilograms whole) of Gulf of Mexico Gray Triggerfish from 2009 through 2012 and from 2014 through 2017. Landings in June and July were excluded due to a seasonal closure implemented in 2013. Landings from after June in 2012 and November in 2017 were excluded due to annual catch limit closures. The trip limit change occurred on June 10, 2013.

Month	Mean 2009–2012	Mean 2014–2017	% Difference
Jan	2,818	1,781	−37
Feb	2,168	2,213	2
Mar	3,561	2,408	−32
Apr	3,701	2,477	−33
May	4,847	2,885	−40
Aug	3,281	1,925	−41
Sep	3,428	2,424	−29
Oct	3,510	2,142	−39
Nov	3,792	2,154	−43
Dec	4,457	2,782	−38

A recent examination by Liu et al. (2016) found that if fishers are restrained by harvest or trip limits they can respond by making more trips to maintain the previous harvest amount, counteracting the desired reduction in harvest rates. A study by Acheson (2001) also found a diverse set of fisher responses to trap limits imposed as a management tool for lobster (family Nephropidae), such as new or latent effort entering the fishery, confounding the goal of reducing overall effort. Acheson (2001) found that the majority of fishers increased their number of traps and additional licenses entered the fishery causing an overall increase in effort. Additionally, Richards (1994) found that fishery-dependent indices based on CPUE were negatively impacted by implementing or changing trip limits, resulting in difficulties when using the indices in stock assessments.

The analysis for South Atlantic Snowy Grouper conducted in Regulatory Amendment 20 accurately predicted the change in landings per trip but failed to account for an increase in the number of trips landing Snowy Grouper early in the fishing season. Commercial harvest of Snowy Grouper has closed in July or earlier since the trip limit increase went into effect as a result of meeting the annual catch limit. Inadvertently, increasing the trip limit for Snowy Grouper in the South Atlantic may have encouraged a derby fishery evident by the increased number of trips when the fishery opened. The increased number of trips landing Snowy Grouper in the South Atlantic (Table 1) may be due to fishers specifically targeting the species since the trip limit increase could have made Snowy

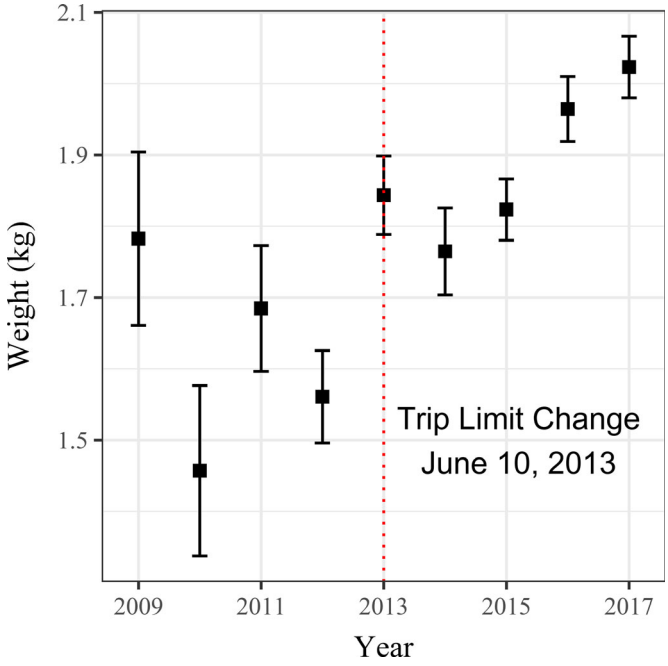

FIGURE 4. The mean weight (kilograms whole; error bars show the 95% confidence intervals) of individual Gray Triggerfish landed in the Gulf of Mexico from 2009 through 2017 based on data from the SEFSC Trip Interview Program. The dashed red line shows when the trip limit change occurred.

Grouper harvest economically beneficial. It likely was not worth targeting Snowy Grouper, which occur far offshore, when the trip limit was 45.4 kg (100 lb) gutted weight, but once the trip limit was increased to 90.7 kg (200 lb) gutted weight, fishers could make a profit from a trip. An examination of the distribution of landings per trip for Snowy Grouper revealed many more trips near the increased 90.7-kg trip limit after implementation (Figure S.5). The South Atlantic Council has approved Regulatory Amendment 27 to the fishery management plan for the Snapper–Grouper Fishery of the South Atlantic Region that, if implemented, would divide the Snowy Grouper quota into two seasons. The South Atlantic Council developed this amendment to provide more access for Snowy Grouper throughout the South Atlantic region and to minimize regulatory discarding from annual catch limit closures when fishermen target co-occurring species like Blueline Tilefish *Caulolatilus microps* (SAFMC 2018). The same amendment adjusts management measures, such as split season quotas, trip limits, and size limits, for other commercially important species in the South Atlantic. Future retrospective analyses could provide insight on how successful these actions were in achieving their goals. Additionally, future retrospective analyses could focus on how changes to management measures for other species could have impacted retention since both of these species can be captured as bycatch.

The analysis for Gulf of Mexico Gray Triggerfish conducted in Amendment 37, on the other hand, failed to account for an increase in the mean weight of fish being landed that could have been due to size selection (high-grading) by fishers in response to the trip limit. Since fishers are limited only by the number of fish, it is economically more efficient to retain the largest fish captured. In this case, there may be a greater number of discards, particularly of smaller fish. Early analyses of trip limits in the U.S. West Coast groundfish fishery by Pikitch et al. (1988) found evidence of high-grading and that the discard rate had an inverse relationship when compared with the magnitude of the trip limit imposed. Evidence of high-grading was also found by Batsleer et al. (2015) in 44 out of 336 papers containing onboard observations, interviews, or self-reported logbook data. The authors determined that high-grading is likely underreported in many fisheries due the difficulty in detecting discards and could potentially undermine the sustainable management of many fish stocks.

Another possible reason why an increase in mean weight was observed for Gray Triggerfish is that the stock may be rebuilding. An updated stock assessment began in May 2019 that could provide more insight into changes in the Gulf of Mexico Gray Triggerfish population. A combination of both high-grading and changes in the population are also possibly the cause of the increase in the mean weight of Gray Triggerfish being landed.

Multiple management measures are used to regulate most fish stocks in the South Atlantic, which makes interpreting the efficiency of each individual management measure difficult to determine. Future analyses could focus on trip limits currently being considered or those that have very recently been implemented for species, such as South Atlantic Red Grouper *Epinephelus morio*, once multiple years of data are available for comparing the predicted and actual changes to harvest. Additionally, retrospective analyses could examine the predicted management changes from other measures, such as size limits or bag limits, for species in the recreational sector.

The results of this research highlight the complicated dynamics that must be accounted for when predicting outcomes from management changes. A simulation model by Gillis et al. (1995) based on the actions of fishers predicted high-grading with restrictive trip limits and recommended moderate or less restrictive limits on trip effort as a better management tool than trip landing limits. There are a myriad of factors present that motivate the decisions of fishers, and not all the diverse effects can be accurately predicted. An evaluation of multiple types of individual management measures, including trip limits, by Liu et al. (2016) found that many management measures individually create unintended consequences, such as developing a derby fishery, increasing discards, or reducing profitability.

Liu et al. (2016) suggested strategically combining individual management measures or developing more rights-based approaches. It is also vital that current fishery monitoring programs remain in place or expand to effectively evaluate changes resulting from management measures, such as increased discards. Currently, in the Gulf of Mexico there is a mandatory observer program, but there is no mandatory reef fish observer program in the South Atlantic to verify fisher self-reported discarded information. Nontraditional monitoring measures being used in other regions of the USA include electronic monitoring through video cameras. Electronic monitoring has been used for catch accounting of some or all species and may provide a cost-saving opportunity to provide coverage or supplement observer coverage with support from the fishers as shown in the other U.S. regions (Gilman et al. 2019). In addition to monitoring discard quantities, recent work by Pulver and Stephen (2019) in the gulf has attempted to discern the reason (size limit, quota limitation, etc.) why discards are occurring to focus future management efforts for reducing discards in the region.

Another factor that is considered when implementing regulations in fisheries is the economic response that occurs when fishing is either restricted or released. Weninger and Waters (2003) found that trip limits increased the harvest costs substantially in the Gulf of Mexico reef fish fishery, leading to increased economic inefficiency. Since trip limits often constrain harvest, fishers are required to make more trips to maintain their previous level of catch if the price of the catch remains the same. Additional trips could lead to safety concerns since more time spent at sea increases the chance of an accident occurring (Marvasti 2017). When trip limits, gear restrictions, and spatial closures were replaced with other alternatives, such as an individual transferrable quota system, Branch (2006) found that total revenue increased and discards were reduced. Similarly, research in West Coast fisheries found a 79% decrease in the average rate of fishing on high-wind days after a rights-based catch shares management system was implemented, leading to a safer fishery (Pfeiffer and Gratz 2016). A rights-based individual fishing quota (IFQ) system had been in place for a number of years for some species in the gulf, such as Red Snapper *Lutjanus campechanus* and Red Grouper. Recent review of two IFQ programs in the gulf found similar results as Branch (2006), with increased economic efficacy and discards generally decreased after implementation of the IFQ programs (GMFMC 2013, 2018).

Based on the results of this study, managers should be cautious when attempting to balance multiple management goals, such as biological, economic, and social components. Zhou et al. (2010) found a balanced-exploitation approach that promotes less selective fishing could support more sustainable fisheries by reducing pressure on key species. Management strategy evaluation methods have been effective in many regions and offer a promising framework to examine diverse strategies in the multispecies fisheries in the southeastern USA (Smith et al. 1999; Fulton et al. 2014). Regardless, a more ecosystem-based fishery management approach is already underway in both regions, and this research should contribute to the ability of managers to make more informed decisions, increasing long-term sustainability. For future trip limit analyses, it is recommended that effort compression and changes in the mean weight of fish being landed when the limit is in numbers of fish be considered.

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SUPPORTING INFORMATION

Additional supplemental material may be found online in the Supporting Information section at the end of the article.