Factors that Influence Discarding in the Gulf of Mexico Commercial Grouper-Tilefish IFQ Reef Fish Fishery

Jeffrey R. Pulver[1], and Jessica A. Stephen[1]

[1] National Marine Fisheries Service, Southeast Regional Office, 263 13th Avenue South, St. Petersburg, FL 33701.

Corresponding author Jeffrey R. Pulver (email: jeff.pulver@noaa.gov)

Pulver, J.R., Stephen, J.A., 2019. Factors that Influence Discarding in the Gulf of Mexico Commercial Grouper-Tilefish IFQ Reef Fish Fishery. Fisheries Research 218, 218–228. https://doi.org/10.1016/j.fishres.2019.05.018

Abstract

Factors potentially affecting fish discarding were evaluated for species managed under the Gulf of Mexico grouper-tilefish individual fishing quota (GT-IFQ) program. Thirteen commercially important species are managed under the GT-IFQ program. Some of the more commonly caught species in the program include red grouper (*Epinephelus morio*), gag (*Mycteroperca microlepis*), speckled hind *(Epinephelus drummondhayi*), golden tilefish (*Lopholatilus chamaeleonticeps*), and blueline tilefish (*Caulolatilus microps*). It is necessary to determine why discards are occurring to develop a future discard mitigation strategy. Logistic models were constructed using data from the Southeast Fisheries Science Center's (SEFSC) Reef Fish Observer Program (RFOP) with covariates of fish length, available allocation, gear type, calendar year quarter, and year to infer reasons for discarding. The results from RFOP models in conjunction with self-reported discard information from the SEFSC Supplemental Discard Logbook program determined that discarding due to fish length selection, not related to minimum a size limit, is occurring for golden tilefish, speckled hind, yellowedge grouper (*Epinephelus flavolimbatus*), and snowy grouper (*Hyporthodus niveatus*). Other dynamics such as multi-species quota discarding are likely responsible for discards of blueline tilefish. Based on the results of the study, potential changes to the GT-IFQ program such as additional flexibility measures were identified as potential management strategies for decreasing discards. A similar approach to inferring why discarding is occurring could be used in the other regions for more effective management promoting long-term sustainability of valuable fisheries.

1. Introduction

The commercial reef fish fishery in the Gulf of Mexico (Gulf) is a multi-species fishery primarily targeting groupers (*Epinephelus* sp. and *Mycteroperca* sp.), snappers (*Lutjanus* sp. and *Rhomboplites* sp.), and tilefishes (*Lopholatilus* sp. and *Caulolatilus* sp.) using two primary gear types, bottom longline and vertical line (handline or bandit). Based on observer program coverage of the Gulf commercial reef fish fishery, Scott-Denton et al. (2011) identified 183 taxa captured with bottom longline and 178 taxa with vertical line gear. A comprehensive Gulf fishery-independent sampling by Murawski et al. (2018) using bottom longline gear found similar results to the observer program when comparing species assemblages, species richness, and size composition of select species. High species diversity in the reef fish fishery, in combination with multiple fishing gear types and methods, results in the incidental captures of non-target (bycatch) or undersized species. Of fundamental concern to fishery managers is the contribution of discards to the overexploitation of stocks, in not only the Gulf, but also worldwide (Sissenwine et al., 2014). Managers are often required to protect stocks from overexploitation by restricting harvest through measures such as size limits, seasonal or area closures, or limiting participation. However, management measures may not fully protect stocks since discarding may still occur. Within the past decade, management for many Gulf reef species has shifted from a "derby" style fleet-wide quota to an individual fishing quota (IFQ) system for each permit holder based on historical landings for several species. The IFQ program for grouper-tilefish (GT-IFQ) has several built-in flexibility measures to accommodate the multi-species nature of the commercial reef fish fishery intended to reduce discards.

The GT-IFQ program established in 2010 includes five share categories: gag, red grouper, other shallow-water groupers (SWG), deep-water groupers (DWG), and tilefishes (TF). Each GT-

IFQ share category has distinct shares and associated allocations. Shares are percentages of the commercial quota, while allocation refers to the poundage that may be possessed, landed, or transferred during a given calendar year. At the start of each calendar year, allocation is distributed to IFQ shareholder accounts and if not used expires at the end of the year. Additionally, discards do not count against the amount of allocation held. The amount allocated to an account is based on the share percentages of the annual quota held by a GT-IFQ shareholder. Two share categories, gag (*Mycteroperca microlepis)* and red grouper (*Epinephelus morio*), have a multi-use provision that allows a portion of the red grouper quota to be harvested under a portion of the gag allocation, or vice versa. The multi-use provision for gag and red grouper is calculated using the buffer between each quota and annual catch limit provided neither species is in a rebuilding plan and can only be used until the species-specific quota is landed or transferred. The three remaining share categories, SWG, DWG, and TF are multiple-species categories, designed to capture species complexes that are commonly caught together (Table 1). Three grouper species (scamp (*Mycteroperca phenax)*, warsaw grouper (*Epinephelus nigritus*), and speckled hind (*Epinephelus drummondhay*i) are found in both the shallow and deep-water complexes. Flexibility measures in the GT-IFQ program allow these species to be landed under both share categories. Scamp are designated as a SWG species, but may be landed using DWG allocation once all SWG allocation in an account has been harvested. Warsaw grouper and speckled hind are designated as DWG species and may be landed using SWG allocation after all DWG allocation in an account has been harvested. Also, a one-time overage provision exists for all share categories allowing fishers to land up to 10% greater than their remaining allocation on a trip provided they possess shares in that category and the allocation is automatically deducted in the subsequent year.

Even with multi-use, flexibility measures, and overage provisions discarding due to minimum size limits, high-grading for a species, or grading among a species group (share category) could occur. 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. Multi-species quota discarding or grading between groups is often due to price differentials between species in multi-species IFQ categories, e.g., retaining more valuable species and discarding less valuable ones. Branch (2009) found that high-grading and grading among a species group often declined under an individual transferrable quota management system, but may increase without effective enforcement or if the catches are not counted against the quota. Batsleer et al. (2015) found evidence of high-grading in 44 out of 336 papers containing onboard observations, interviews, or self-reported logbook data. The authors concluded that high-grading is likely under-reported in many fisheries due the difficulty in detecting discards and could potentially undermine the sustainable management of many fish stocks. Grading among a species group is also likely difficult to detect without onboard observation, but evidence that it is occurring between tilefish species in the Gulf, potentially due to price differentials, was reported by Pulver et al. (2016).

Quantifying discards can be accomplished through self-reporting mechanisms or more accurately by onboard fishery observers. Similar to other studies, the National Marine Fisheries Service (NMFS) Southeast Fisheries Science Center (SEFSC) reef fish observer program (RFOP) currently monitors the Gulf commercial reef fish fishery recording detailed information such as lengths and dispositions (kept or discarded) of individual fish captured on randomly selected trips (1% to 6% based on the number of days at sea). Using information collected by the RFOP, this study examined the influence of fish length, available allocation, gear type, calendar year quarter, and year on discarding of GT-IFQ species. In addition, the RFOP results were compared to fisher's self-reported discard information collected by the SEFSC Supplemental Discard Logbook program for comparison and validation. In combination, the output from both of these approaches can provide insight into fisher's behavior that can be used to develop successful discard mitigation strategies in the future.

2. Methods

2.1 Reef Fish Observer Program Data

The NMFS SEFSC began a mandatory observer program with partial coverage to characterize the commercial reef fish fishery in the Gulf in July 2006 (Scott-Denton et al., 2011). Prior to 2006, the only observer coverage of the commercial reef fishery was a voluntary NMFS observer program conducted from 1993 through 1995. For the Gulf RFOP, vessels were randomly selected quarterly each year to carry an observer on a subset of trips. Sampling effort was stratified by season and gear in the eastern and western Gulf based on annually updated vessel logbook data (Scott-Denton et al., 2011). Increased observer coverage levels were directed at the bottom longline portion of the reef fish fishery in the eastern Gulf starting in February 2009, due to concerns regarding sea turtle interactions. Additionally, in 2011, increased funding allowed enhanced coverage of both the vertical line and bottom longline sectors through 2014. Because of these actions, observer coverage levels did not remain consistent throughout the years, but varied depending on funding levels. Fishery observer data collected using standardized sampling protocols from January 2010 through December 2017 were used in the analyses (NMFS, 2016).

Fishery observers on reef fish vessels assigned one of the following dispositions to each fish captured by the vessel: kept, used for bait, discarded alive, discarded dead, discarded unknown if dead or alive, and unknown if kept or discarded. Only fish recorded as kept or discarded (alive, dead, or unknown) were used in the analyses to model discard factors. All fish lengths were converted to total length in inches using species-specific conversion equations when necessary to coincide with existing any minimum size limit regulations in place. In addition to data recorded by the RFOP, it was necessary to merge the amount of GT-IFQ allocation available for each share category during each fishing trip since it may be a potential factor influencing discarding. Data from the Southeast Regional Office GT-IFQ database (accessed April 25, 2018) were merged with the RFOP data (accessed April 30, 2018) to provide the maximum amount of allocation for each of the five share categories available on the last day of the fishing trip. It is possible that additional allocation could be added after the conclusion of the fishing trip and before offloading the catch, but it was not possible to account for all scenarios in these analyses. The available allocation amounts in pounds were binned into three categories of: 1) no allocation available, 2) low amount of allocation available, and 3) high amount of allocation available. The high and low available allocation categories were determined using the median allocation available of each share category for the observed fishing trips.

2.2 RFOP Statistical Analyses

A generalized additive model (GAM) with binomial distribution and log-link was fit for each GT-IFQ species using the *mgcv* package in R (Wood, 2011) to determine which variables were influencing discarding. A GAM was preferred due to the unbalanced observations for the explanatory variables in the RFOP data and a similar approach was successful by Feekings et al. (2012) when investigating factors affecting discards in a Danish trawl fishery (Hastie and Tibshirani 1990; Zuur et al., 2009). Stepwise backwards selection was used to remove non-significant ($P > 0.05$) covariates using the "anova.gam" function to determine variable significance at each step. For the smoothed terms, P values proximal to 0.05 were included since the value is approximate. For gear types, vertical line gear includes all vertical line gear (e.g., hand lines, bandit reels, hook and line) as well as miscellaneous gear (e.g., spearfishing), while bottom longline gear did not include any other gear types. Quarter is calendar year quarter (e.g., January 1 through March 31). Quarter was used because it was theorized that available allocation may be used differently throughout the year since it expires at the end of the year or other seasonal trends may be present. The available allocation used depended on the share category associated with the GT-IFQ species. Each initial logistic GAM was fit to the binary response of kept or discarded modeled as;

$$Logit(Y_i) \sim s(Total\ Length_i) + \beta_1 Allocation\ Bin_i + \beta_2 Gear\ Type_i + \beta_3 Quarter_i + \beta_4 Year_i \qquad (1)$$

where Y is each individual fish (i), s is a thin plate smoothing spline, β are the estimated model coefficients and no intercept was included. The number of knots was determined using the automated method of generalized cross-validation with the "gam" function in the *mgcv* package. The smoothing dimension or number of knots (k) for length was increased if necessary, so it was not restrictively low using the "gam.check" function in the *mgcv* package to compare k to the estimate degrees of freedom. Interactions between terms were not explored for each GAM since it may have made interpretation of the results problematic. The percent of deviance explained, adjusted R^2, the area under the receiver operating characteristic curve (AUC), and significant variable(s) remaining in each model were reported. The AUC is a measure of overall model predictive accuracy, with 0.5 considered random and 1.0 a perfect fit (Agresti, 2013).

Validation of the logistic GAM model included examining the quantile-quantile (Q-Q) plots of reference quantiles with simulated deviance residuals, Q-Q plots of reference quantiles with Pearson residuals, histograms of the Pearson residuals, checking the Pearson residuals against the fitted values for violations of constant variance, and a comparison of the fitted versus observed values (Zuur et al., 2009). The predicted discard probability for each species with 95% confidence intervals were then plotted and visually examined for patterns in effect among species. All predicted discard probabilities use the medians for continuous variables and the most common factor for categorical variables of the aggregated data. The confidence intervals were calculated using the standard errors based on the Bayesian posterior covariance matrix for the parameters of the fitted GAM object.

In addition to logistic GAMs, boosted regression trees were used to examine the influence of the same variables on discarding. Boosted regression trees are a powerful method for cross-validating predictor variables compared with traditional tree regression by applying a model averaging technique where the influence of predictor variables is determined using stochastic gradients flexible enough to include nonlinearities and complex interactions (De'ath, 2007; Elith et al., 2008). The same predictor variables of total length, year, quarter, allocation bin, and gear type were included in each boosted logistic regression tree model. The tree complexity was fixed at four and the tuning parameters of the learning rate (0.01-0.001), bag fraction (0.5-0.75), were adjusted in the model fitting process. To prevent overfitting, the data were divided into 10 subsets and cross-validation was used to determine the optimal number of trees for minimizing the holdout deviance with the "gbm.step" function in the *gbm* package of R with a Bernoulli distribution (Ridgeway, 2018). For each model, the relative importance for each predictor variable was reported as their contribution scaled to 100. In addition, the relative strength of interactions between variables, AUC, and percent of deviance explained were reported for each species. For model validation, the residuals for models were plotted using a histogram to detect model fit and the fitted values were compared against each predictor. Finally, all analyses in this research were performed using R statistical software (version 3.4.2; R Core Team 2017).

2.3 Supplemental discard logbook

There are concerns about the accuracy of self-reported fisher logbook data in collecting discard information. Biases associated with logbooks primarily result from inaccuracy in reporting of species that are caught in large numbers or are of little economic interest (particularly of discarded species), and from low compliance rates. While not directly to related to the Gulf reef fish fishery, other studies examining self-reported fisher catch and discard data estimates found they were similar to observer or research data as long as a rigorous quality control system is in place (Fox and Starr, 1996; Starr, 2010). Since this study is focused primarily on inferring discards drivers, and not the magnitude of discarding, it was surmised the SEFSC self-reported logbook data would be useful in augmenting the modeling efforts. Currently, the SEFSC collects commercial discard data using a supplemental form that is sent to an approximately 20% stratified random sample of the active permit holders in the Gulf reef fish fishery. In addition to the number of self-reported discards per trip and gear, the SEFSC Supplemental Discard Logbook attempts to quantify the reason why discarding occurs using four codes (SEFSC, 2018).

1. Regulation – Not legal size: Animals that would have been sold; however, local or federal size limits forbid it.
2. Regulation – Out of season: Animals that would have been sold; however, the local or federal fishing season is closed.
3. Regulation – Other: Animals that would have been sold; however, a local or federal regulation other than size or season, forbids it (other than size or season; i.e., protected species, not properly permitted, lack of allocation).
4. Market conditions: Animals that have no market value (rotten, damaged).

Fishers can specify multiple reasons for a species discarded on the same trip and gear. Even though the discard logbook may not be representative of the entire reef fish fishery, it may provide similar insights when compared to the RFOP about why discarding occurs for GT-IFQ managed species. Supplemental Discard Logbook data (accessed May 31, 2018) from 2010 through 2017 in the Gulf were used for comparison to the RFOP logistic models developed with data from the same time period by determining the proportion of discards that occurred for each reason by species.

3. Results

A wide range of captures was observed by the RFOP from January 2010 through December 2017 for the GT-IFQ managed species. The number of GT-IFQ captures ranged from a minimum of nine yellowfin grouper (*Mycteroperca venenosa*) to 444,183 red grouper (Table 2). Scamp and yellowedge grouper (*Epinephelus flavolimbatus*) captures by far accounted for the majority of observed in the SWG and DWG share categories, respectively. Golden tilefish (*Lopholatilus chamaeleonticeps*) accounted for approximately 77% of the tilefish (TF) share category captures with blueline tilefish (*Caulolatilus microps*) accounting for almost all the rest. A low discard percentage (<10%) was observed for all species in the SWG and DWG share categories except speckled hind (25.9%). Gag, red grouper, and all the tilefish species had a higher percentage of discards observed than SWG and DWG. The highest percentage of discards occurred for blueline and goldface tilefish (*Caulolatilus chrysops*), but blueline tilefish discards were observed in much greater numbers.

For nine GT-IFQ species with enough observations, a logistic GAM was fit to the RFOP data. The percentage of deviance explained ranged from a minimum of 14.8% for blueline tilefish to a maximum of 85.6% for black grouper (Table 3). The lower adjusted R^2 values, especially for snowy grouper, indicate poorer model fits. All the AUC values were >0.75 indicating very good model predictive accuracy, with the largest values observed for red grouper (0.99) and black grouper (0.99). All variables were significant in the final models except for snowy grouper (*Hyporthodus niveatus*) in which year was removed, and black grouper that only had length and available allocation retained as significant covariates. Acceptable fits were indicated on all diagnostic plots (Figs S.1-S.3).

The individual logistic GAMs predicted an increase in the odds of discarding for shorter total lengths of eight GT-IFQ species (Fig. 1). The influence of minimum size limit requirements were evident for red grouper, gag, and scamp by the steep declines in the predicted probability of discarding near those values. Some scamp under the minimum size limit were being retained decreasing the predicted probability of discarding for smaller sized individuals. An increase in allocation available lowered the predict odds of discard probability for the majority of the species (Fig. 2). However, low allocation amounts had a higher predicted probability compared to no allocation available for gag and blueline tilefish. For the majority of the species, a general trend in decreasing probability of discarding since the beginning of the GT-IFQ program was evident (Fig. 3). A decrease in the predicted probability of discarding in the later quarter of the year was the general trend for all species except blueline tilefish (Fig. 4). Blueline tilefish had the lowest predicted discard probability in the first quarter of the year and much higher predicted values in subsequent quarters. The predicted probability of discarding by gear type varied across species (Fig. 5). Red grouper, gag, snowy grouper, and golden tilefish all had higher predicted discards occurring when bottom longline gear was used compared to vertical line gear.

Similar to the logistic GAMs, a high percentage of deviance was explained in all the final boosted logistic regression tree models ranging from 53.5% for blueline tilefish to 93.2% for black grouper (Table 4). The boosted logistic regression tree AUC values were slightly higher than the

GAMs ranging from 0.92 to 0.99 indicating excellent predictive accuracy. Similar predicted changes in discard probability were observed for each predictor variable when compared to the logistic GAMs (Figs S.4 - S.8). The length of the fish was the predictor with the largest influence on whether an individual was discarded for all GT-IFQ species modelled except blueline tilefish (Fig. 6). Blueline tilefish had year as the predictor with the largest influence followed by quarter, allocation bin, and length. Depending on the species, year or available allocation had the next largest relative influence on discarding of GT-IFQ species. The quarter of the year had the largest relative influence for blueline tilefish and golden tilefish compared to the other species. The gear type used for capture had the lowest relative influence on discarding for almost all the species. The interaction strength between variables had a similar pattern with length strongly interacting with other variables for most species followed by year and available allocation (Fig. S.9).

Similar to the RFOP, the SEFSC Supplemental Discard Logbook also had a wide range of self-reported discards from 2010 through 2017 with a maximum of 458,928 for red grouper reported to no discards reported for yellowfin grouper, yellowmouth grouper (*Mycteroperca interstitialis*), and goldface tilefish (Table 5). Fishers reported not legal size as the reason for the majority of discards for red grouper, gag, scamp, snowy grouper, yellowedge grouper, and golden tilefish. Out of season was rarely selected as discard reason. Other regulations were selected often as the discard reason for most species and was the dominant reason selected for black grouper, speckled hind, and warsaw grouper. Market condition was the dominant reason selected for blueline tilefish, but also was selected as the reason for >25% of the discards for speckled hind, yellowedge grouper, and golden tilefish.

4. Discussion

An IFQ or a similar catch share management program should not be the only management measure to ensure sustainability of a fishery. Rather, it should be one tool used in concert with other management measures. The use of an IFQ management program as one of many tools in the toolbox was supported by Chu (2009) who examined IFQ programs worldwide finding some stocks still declined after implementation of the programs. Chu (2009) specifically recommended more effective annual catch limits, enforcement, and monitoring were needed for stock recovery even with an IFQ management system in place. Other programs such as the Pacific West Coast Groundfish Trawl Catch Share Program have required 100% observer coverage since the program was initiated to improve sustainability through more accurate accounting of discards, but also to ensure compliance (PFMC, 2010). Prior to implementation of the GT-IFQ program, discards of species now included in the program were primarily due to size limits, trip limits, and seasonal closures. After the implementation of the GT-IFQ program, trip limits and seasonal closures were eliminated for species in the five share categories, except for the restriction of longline gear inside the 35-fathom contour from June through August in the eastern Gulf. Fishers are now constrained by the GT-IFQ allocation they possess for each share category. Fishers without large amounts of shares or allocation must discard GT-IFQ species when the allocation in their account is exhausted or obtain additional allocation from other allocation holders to continue to harvest GT-IFQ species. The GT-IFQ program's built-in multi-use, flexibility measures, and overage provision were intended to reduce discards and discard mortality.

Five species in the GT-IFQ program have minimum size limits in place for the duration of the program that may be the reason for discarding: gag, red grouper, black grouper, scamp, and yellowfin grouper. For red grouper, the most commonly landed and discarded GT-IFQ species, the current minimum size limit is the greatest reason discarding is still occurring under the GT-IFQ program. Red grouper length was the variable with the greatest relative influence in the boosted logistic regression model and length's influence was evident in the steep decline in discarding predicted by the logistic GAM near the minimum size limit. In addition, the minimum size limit was the reason for >94% of red grouper reported discarded to SEFSC Supplemental Discard Logbook. For the other GT-IFQ species, the boosted logistic regression models identified fish length as the primary influence on discarding for all the species except for blueline tilefish. Length was also chosen a high percentage of the time as the reason for discarding in the SEFSC Supplemental Discard Logbook. There is no commercial minimum size limit for golden tilefish, yellowedge grouper, or snowy grouper, but self-reported information from the SEFSC Supplemental Discard Logbook indicated that the minimum size limit as the most common discard reason for these species. One reason discarding of legal sized fish may be occurring is high-grading due to price differentials between different sized fish. Currently price data on different size categories is unavailable in the Gulf, but price data collected from 2012 through 2016 for golden tilefish in the mid-Atlantic revealed higher prices for larger size categories (MAFMC, 2017). The small category for golden tilefish averaged $2.77 per pound compared to $4.23 per pound for the large category. Similar dynamics may be present in the Gulf leading to the increased discards of smaller golden tilefish due to price differentials as well as snowy grouper and yellowedge grouper. Further research could focus on the impact of different discard size selectivity on management for the species identified in this study since other research by Kindsvater et al. (2017) found a number of undesirable consequences due to fishery selectivity for reef fish, especially hermaphroditic grouper species.

The amount of available allocation had the predicted effect of lowering the discard probability as the amount increased for most species in the logistic GAM models except for blueline tilefish and gag (Fig. 2). This coincides with the expectation that fisher are less likely to discard if not constrained by allocation. However, blueline tilefish and gag had higher predicted discard probabilities when comparing the low amount to no available allocation. The prediction of discarding at lower amounts of allocation for blueline tilefish could be due to multi-species quota discarding resulting from the preference of fishers to use a limited amount of available allocation for the higher valued species of golden tilefish. In 2016, the average ex-vessel price for blueline tilefish was $1.78 per pound compared to the higher value of $3.09 per pound for golden tilefish (SERO, 2016). Furthermore, fishers selected market condition for >76% of the discarded blueline tilefish even though the species does have market value, but selecting market value as the reason could be due to the preference of retaining the higher valued golden tilefish species. The reason for higher predicted gag discards in the low allocation bin could be due to a significant quota reduction in 2011 even though year was included in the models. Fishers could be choosing to discard gag when they only have limited amount of allocation available until retention is needed to produce a profitable trip or when other more favorable economic conditions not identified are influencing behavior.

Market conditions was also selected for >25% of discards for speckled hind, yellowedge grouper, and golden tilefish potentially due to the preference of larger and possibly more valuable sized individuals. It was considered that market value was being selected due to damage from predation by sharks, other finfish, or marine isopods, but the RFOP only indicated damaged fish on a very low percentage (<1%) of discards. In addition to the amount of available allocation on a fishing trip, it was theorized that allocation might be used differently throughout the year since any unused allocation expires at the end of the calendar year and seasonal economic dynamics may be present (e.g., increased tourism or market saturation from the South Atlantic snapper grouper fishery). A decrease in the predicted probability of discarding in the later quarters of the year was the general trend for almost all species, likely due to unused allocation expiring at the end of the year. In addition, it may be more difficult for fishers to obtain allocation through transfers near the end of the calendar year, resulting in fewer trips and more discards occurring. The opposite trend was predicted for blueline tilefish with the lowest discarding predicted to occur in the first quarter with higher values in the subsequent quarters for unknown reasons, but may be related to a fisher's preference to use the tilefish allocation for golden tilefish instead of blueline tilefish when targeting other deep-water species.

One of the goals of the GT-IFQ program was to promote fishery conservation and management over the duration of the program by reducing discards. Due to the multi-species nature of the fishery, it was hoped that allocation could move to fishers capturing species that had been previously discarded as bycatch. For the majority of the species, a general trend in decreasing probability of discarding across years since the beginning of the GT-IFQ program was evident in the logistic GAMs. For scamp, yellowedge grouper, golden tilefish, and blueline tilefish the highest predicted probability of discarding was in 2010. The restriction in quota for gag in 2011 was evident as a spike in the predicted discard probability followed by a general decline in subsequent years as the gag quota was increased. Some of the annual variation could be an artifact of the low RFOP partial coverage levels (1% to 6% based on the number of days at sea) since fewer vessels target some deep water species like blueline tilefish and golden tilefish compared to species that occur in shallower water like red grouper and gag. An examination of observer programs by Benoît and Allard (2009) found evidence of deployment (e.g., observers not randomly distributed on fishing trips) and observer effects (e.g., observed trips do not represent unobserved trips) for observer programs with partial coverage in the Gulf of St. Lawrence fisheries. In the absence of complete or 100% observer coverage in the Gulf reef fish fishery, it is not possible to determine if biases exist in data collected by the RFOP. However, since study focused on the reason discarding is occurring versus the magnitude, it is believed the RFOP results are strongly representative of the fishery, especially with the self-reported logbook information included.

A recent five-year review of the GT-IFQ program examining data through 2014 found the program has provided year-round fishing opportunities to participating commercial fishermen for all grouper and tilefish species included in the GT-IFQ program (GMFMC, 2018). The GT-IFQ program has successfully met its objectives relative to discard reduction for red grouper. After the implementation of the GT-IFQ, red grouper discards and discard ratios significantly decreased across the Gulf and for all gear types. Any future management changes targeted at reducing discards of red grouper could focus on the minimum size limit or total catch accountability management where discards are either mandatorily retained or counted against the quota. Total catch accountability management is not without challenges since recent studies have found discrepancies in its effectiveness based on vessel size with smaller vessels unable to adapt and only larger vessels benefitting (van Helmond et al., 2016). Likewise, the five-year review found gag discards and discard ratios increased in 2011 but declined afterwards as the gag quota increased. The review also found gag and red grouper multi-use shares were not as effective as anticipated and recommended the program could be streamlined by eliminating them. However, the review did conclude the SWG and DWG multi-use, as well as the overage provisions, should be maintained as they effectively contributed to the reduction of GT-IFQ discards. Additionally, recent research by Ropicki et al. (2018) into the other IFQ program currently operating in the Gulf for red snapper (*Lutjanus campechanus*) found the management style has been successful in many of its major goals. However, Ropicki et al. (2018) did identify a number of socioeconomic concerns suggesting modifications such as increasing share ownership by harvesters, limiting consolidation, and increasing harvest flexibility to improve the program.

For the Gulf reef fish species with recent stock assessments, discards and discard mortality are currently accounted for. The stock status was either not overfished or unknown at the end of 2018 for all the species or species complexes in this research (NOAA, 2019). A similar approach as this study could be used in other regions for more effective management by inferring why fish are being discarded and developing management strategies for reducing discards. Based on the RFOP and self-reported logbook data, an opportunity exists for changes in management to address the discarding of blueline tilefish through refinements such as additional flexibility measures or species-specific share categories. Woods et al. (2017) using bioeconomic models to examine IFQ species transformation provisions (e.g., conversion of allocation for one species to another at a prescribed rate) found a number of caveats must be met for the provisions to aid management unless the only goal was to maximize profit. Additional measures such as mandatory retention (discard ban) may be needed to reduce discarding of smaller sized fish of GT-IFQ species without a minimum legal size limit such as speckled hind. However, discard bans remain controversial as a management policy due to the high level of at-sea monitoring needed and increased selectivity of larger fish (Borges et al., 2016). Future studies could use questionnaires to fishers participating in the GT-IFQ program about why they are discarding specific species similar to work by Cullis-Suzuki et al. (2012) for Gulf red snapper. Additional research could also focus on how interspecific changes in discard rates and selectivity may affect biomass critical to developing a more ecosystem-based management approach as identified by Masi et al. (2018). The GT-IFQ program is intended to provide direct benefits to the marine resource and will continue to evolve to meet its goal of reducing discards.

Acknowledgements

We commend the outstanding efforts of the fishery observers, observer coordinators, and data entry personnel involved in this research effort. Additionally, we are grateful for the efforts of the owners, captains, and crews of the vessels cooperating with the observer and logbooks programs. We also would like to thank John McGovern, Kay Racine, and two anonymous reviewers for reviewing the manuscript. NMFS does not approve, recommend, or endorse any proprietary product or material mentioned in this publication. The scientific results and conclusions, as well as any views or opinions expressed therein, are those of the author(s) and do not necessarily reflect the views of NOAA or the Department of Commerce.

References

Agresti, A., 2013. Categorical Data Analysis. John Wiley and Sons, Hoboken.

Batsleer, J., Hamon, K.G., van Overzee, H.M.J., Rijnsdorp, A.D., Poos, J.J., 2015. High-grading and over-quota discarding in mixed fisheries. Rev. Fish Biol. Fish. 25, 715–736. http://doi: 10.1007/s11160-015-9403-0

Benoît, H.P., Allard, J., 2009. Can the data from at-sea observer surveys be used to make general inferences about catch composition and discards? Can. J. Fish. Aquat. Sci. 66, 2025–2039.

Borges, L., Cocas, L., Nielsen, K.N., 2016. Discard ban and balanced harvest: a contradiction? ICES J. Mar. Sci. 73(6), 1632–1639. http://doi.org/10.1093/icesjms/fsw065

Branch, T.A., 2009. How do individual transferable quotas affect marine ecosystems? Fish Fish. 10, 39–57.

Chu, C., 2009. Thirty years later: the global growth of ITQs and their influence on stock status in marine fisheries. Fish Fish. 10 (2), 217–230. http://doi: 10.1111/j.1467-2979.2008.00313.x

Cullis-Suzuki, S., McAllister, M., Baker, P., Carruthers, T., Tate, T.J., 2012. Red snapper discards in the Gulf of Mexico: Fishermen’s perceptions following the implementation of Individual Fishing Quotas. Mar. Policy 36, 583–591.

De'ath, G., 2007. Boosted regression trees for ecological modeling and prediction. Ecology 88 (1), 243–251.

Elith, J., Leathwick, J.R., Hastie, T., 2008. A working guide to boosted regression trees. J. Anim. Ecol. 770, 802–813.

Feekings, J., Bartolino, V., Madsen, N., Catchpole, T., 2012. Fishery discards: Factors affecting their variability within a demersal trawl fishery. PLoS ONE 7 (4), e36409. http://doi:10.1371/journal.pone.0036409

Fox, D.S., Starr, R.M., 1996. Comparison of commercial and research catch data. Can. J. Fish. Aquat. Sci. 53 (12), 2681–2694.

GMFMC (Gulf of Mexico Fishery Management Council), 2018. Grouper-Tilefish individual fishing quota program five-year review. GMFMC, Tampa, Florida. Available from: http://gulfcouncil.org/wp-content/uploads/B-9a-Grouper-Tilefish-Review-March-2018.pdf

Hastie, T.J., Tibshirani, R.J., 1990. Generalized additive models. Chapman & Hall, London.

Kindsvater, H.K., Reynolds, J.D., Mitcheson, Y.S., Mangel, M., 2017. Selectivity matters: Rules of thumb for management of plate-sized, sex-changing fish in the live reef food fish trade. Fish Fish. 1, 1–16. http://doi: 10.1111/faf.12208

MAFMC (Mid-Atlantic Fishery Management Council), 2017. Golden Tilefish Advisory Panel Information Document. Mid-Atlantic Fishery Management Council, 800 North State Street, Suite 201, Dover, DE 19901. Available from: www.mafmc.org/s/Tilefish-AP-Info-February-3-2017-9xfw.pdf

Masi, M.D., Ainsworth, C.H., Kaplan, I.C., Schirripa, M.J., 2018. Interspecific interactions may influence reef fish management strategies in the Gulf of Mexico. Mar. Coast. Fish. 10, 24–39.

Murawski, S.A., Peebles, E.B., Gracia, A., Tunnell, J.W. Jr., Armenteros, M., 2018. Comparative abundance, species composition, and demographics of continental shelf fish assemblages throughout the Gulf of Mexico. Mar. Coast. Fish. 10, 325–346.

NMFS (National Marine Fisheries Service), 2016. Characterization of the U.S. Gulf of Mexico and southeastern Atlantic otter trawl and bottom reef fish fisheries. Observer Training Manual. NMFS, Southeast Fisheries Science Center, Galveston Lab., Galveston, Texas. Available from:

http://www.galvestonlab.sefsc.noaa.gov/forms/observer/obs_training_manual_12_2015.pdf (accessed 7 June 2017).

NOAA (National Oceanographic and Atmospheric Administration), 2019. Fishery Stock Status Updates. Available from: https://www.fisheries.noaa.gov/national/population-assessments/fishery-stock-status-updates.

PFMC (Pacific Fishery Management Council), 2010. Rationalization of the Pacific Coast Groundfish Limited Entry Trawl Fishery Final Environmental Impact Statement. PFMC, Portland, Oregon. Available from: http://www.pcouncil.org/wp-content/uploads/1_Pacific-Coast-Grounddfish-Limited-Entry-Trawl-Fishery-FEIS.pdf.

Pulver, J.R., Liu, H., Scott-Denton, E., 2016. Modelling community structure and species co-occurrence using fishery observer data. ICES J. Mar. Sci. 73 (7), 1750–1763. http://doi:10.1093/icesjms/fsw033

R Core Team, 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Ridgeway, G., 2018. gbm: Generalized Boosted Regression Models. R package version 2.1.4. Available from: http://CRAN.R-project.org/package=gbm.

Ropicki, A., Willard, D., Larkin, S.L., 2018. Proposed policy changes to the Gulf of Mexico red snapper IFQ program: Evaluating differential impacts by participant type. Ocean Coast. Manage. 152, 48–56.

Scott-Denton, E., Cryer, P.F., Gocke, J.P., Harrelson, M.R., Kinsella, D.L., Pulver, J.R., Smith, R.C., Williams, J.A., 2011. Descriptions of the U.S. Gulf of Mexico reef fish bottom longline and vertical line fisheries based on observer data. Mar. Fish. Rev. 73 (2), 1–26.

SEFSC (Southeast Fisheries Science Center), 2018. Supplemental discard and gear interaction trip report. NMFS, Southeast Fisheries Science Center, Miami, Florida. Available from: https://www.sefsc.noaa.gov/docs/2018_Discard_logbook_v2.pdf

SERO (Southeast Regional Office), 2016. Gulf of Mexico 2016 Grouper-Tilefish Individual Fishing Quota Annual Report. NMFS, Saint Petersburg, Florida.

Sissenwine, M.M., Mace, P.M., Lassen, H.J., 2014. Preventing overfishing: evolving approaches and emerging challenges. ICES J. Mar. Sci. 71 (2), 153–156.

Starr, P., 2010. Fisher-collected sampling data: Lessons from the New Zealand experience. Mar. Coast. Fish. 2, 47–59.

van Helmond, A.T.M., Chen, C., Trapman, B.K., Kraan, M., Poos, J.J., 2016. Changes in fishing behavior of two fleets under fully documented catch quota management: Same rules, different outcomes. Mar. Policy 67, 118–129.

Wood, S.N., 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. J. R. Stat. Soc. 73 (1), 3–36. http://doi:10.1111/j.1467-9868.2010.00749.x.

Woods, P.J., Holland, D.S., Punt, A.E., 2016. Evaluating the benefits and risks of species-transformation provisions in multispecies IFQ fisheries with joint production. ICES J. Mar. Sci. 73 (7), 1734–1773. http://doi:10.1093/icesjms/fsw031

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., Smith, G.M., 2009. Mixed effect models and extensions in ecology with R. Springer Science, New York. http://doi:10.1007//978-0-387-87458-6.

Table 1: Gulf of Mexico commercial reef fish IFQ species by share category.

IFQ Share Category	Species[1]
Red Grouper (RG)	Red grouper[2]
Gag (GG)	Gag[2]
Shallow-water Grouper (SWG)	Black grouper Scamp[3] Yellowfin grouper Yellowmouth grouper
Deep-water Grouper (DWG)	Snowy grouper Speckled hind[3] Warsaw grouper[3] Yellowedge grouper
Tilefishes (TF)	Blueline tilefish Golden tilefish Goldface Tilefish

[1] The following species were removed in 2012: rock hind (SWG), red hind (SWG), misty grouper (DWG), anchor tilefish (TF), and blackline tilefish (TF).

[2] RG or GG can be landed under multi-use allocation.

[3] Flexibility measures present. Species can be landed under either SWG or DWG once all allocation is exhausted in one category.

Table 2: The number of captures and percentage for each disposition observed by the RFOP from 2010 through 2017 for GT-IFQ species by share category.

	Number Observed	**Kept**	**Discarded**	**Unknown**
Red Grouper	444,183	60.3%	39.7%	0.0%
Gag	19,177	71.6%	28.3%	0.0%
Shallow-water Grouper				
Scamp	14,940	94.5%	5.4%	0.1%
Black Grouper	387	91.0%	9.0%	0.0%
Yellowmouth Grouper	55	100.0%	0.0%	0.0%
Yellowfin Grouper	9	100.0%	0.0%	0.0%
Deep-water Grouper				
Yellowedge Grouper	29,503	98.7%	1.3%	0.0%
Snowy Grouper	4,804	98.1%	1.9%	0.0%
Speckled Hind	2,000	74.1%	25.9%	0.0%
Warsaw Grouper	280	97.9%	2.1%	0.0%
Tilefishes				
Golden Tilefish	33,628	81.7%	18.3%	0.0%
Blueline Tilefish	9,885	55.3%	44.7%	0.0%
GoldfaceTilefish	130	39.2%	60.8%	0.0%

Table 3. The percent of deviance explained, adjusted R^2, the area under the receiver operating characteristic curve (AUC), and significant ($P < 0.05$) variables remaining in each final logistic GAM model.

Species	**Deviance Explained**	**Adjusted R^2**	**AUC**	**Significant Variables**
Red Grouper	80.5%	0.84	0.99	Length, Allocation Bin, Year, Quarter, Gear
Gag	61.0%	0.65	0.96	Length, Allocation Bin, Year, Quarter, Gear
Black Grouper	85.6%	0.86	0.99	Length, Allocation Bin
Scamp	53.2%	0.49	0.95	Length, Allocation Bin, Year, Quarter, Gear
Snowy Grouper	18.0%	-0.05	0.90	Length, Allocation Bin, Quarter, Gear
Speckled Hind	40.4%	0.42	0.91	Length, Allocation Bin, Year, Quarter, Gear
Yellowedge Grouper	35.0%	0.23	0.90	Length, Allocation Bin, Year, Quarter, Gear
Blueline Tilefish	14.8%	0.19	0.75	Length, Allocation Bin, Year, Quarter, Gear
Golden Tilefish	38.8%	0.43	0.91	Length, Allocation Bin, Year, Quarter, Gear

Table 4. The percent of deviance explained and the AUC for each boosted logistic regression tree model.

Species	**Deviance Explained**	**AUC**
Red Grouper	82.4%	0.99
Gag	71.0%	0.97
Black Grouper	93.2%	0.97
Scamp	70.7%	0.97
Snowy Grouper	76.0%	0.97
Speckled Hind	59.5%	0.93
Yellowedge Grouper	53.6%	0.94
Blueline Tilefish	53.5%	0.92
Golden Tilefish	55.6%	0.95

Table 5. The number of discards, number of trips reporting discards, and percentage of discards for each discard reason out of the total number for each GT-IFQ species reported to the SEFSC Supplemental Discard Logbook from 2010 through 2017.

IFQ Species	**Number Reported**	**Number of Trips**	**Not Legal Size**	**Out of Season**	**Other Regulation**	**Market Conditions**
Red Grouper	458,928	4,986	94.72%	0.10%	4.50%	0.69%
Gag	37,062	2,499	55.97%	2.06%	40.73%	1.24%
Black Grouper	1,516	123	40.96%	5.80%	52.90%	0.33%
Scamp	4,077	582	65.49%	0.29%	33.80%	0.42%
Snowy Grouper	512	18	67.77%	0.00%	12.70%	19.53%
Speckled Hind	234	18	16.67%	0.85%	53.85%	28.63%
Warsaw Grouper	18	10	27.78%	0.00%	61.11%	11.11%
Yellowedge Grouper	1,066	42	45.87%	0.00%	20.36%	33.77%
Blueline Tilefish	8,999	57	0.21%	0.32%	22.78%	76.69%
Golden Tilefish	2,725	37	50.46%	0.00%	20.11%	29.43%

List of Figures

Figure 1. The discard probabilities predicted by the GAM logistic regression model from total length with 95% confidence intervals. All model probability predictions use the medians for continuous variables and the most common level for categorical variables. Species with a minimum size limit have that value included for reference.

Figure 2. The discard probabilities predicted by the GAM logistic regression model for each allocation bin (none, low, or high) with 95% confidence intervals.

Figure 3. The discard probabilities predicted by the GAM logistic regression model for each year with 95% confidence intervals.

Figure 4. The discard probabilities predicted by the GAM logistic regression model for each calendar year quarter with 95% confidence intervals.

Figure 5. The discard probabilities predicted by the GAM logistic regression model for each gear type with 95% confidence intervals.

Figure 6. The relative influence for each variable affecting discarding from the boosted logistic regression tree models for nine of the GT-IFQ species.

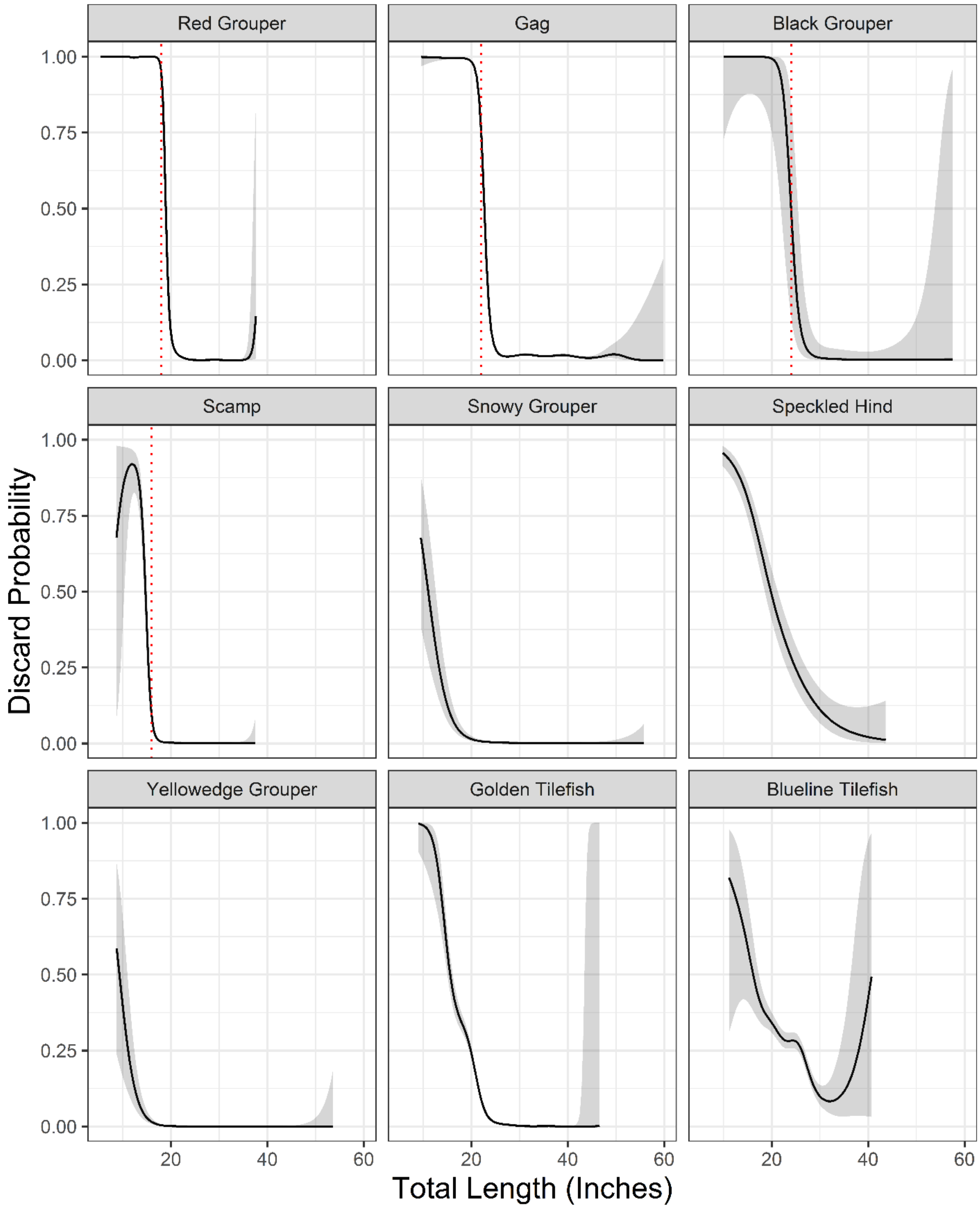

Figure 1. The discard probabilities predicted by the GAM logistic regression model from total length with 95% confidence intervals. All model probability predictions use the median for continuous variables and the most common level for categorical variables. Note species with a minimum size limit have that value included for reference.

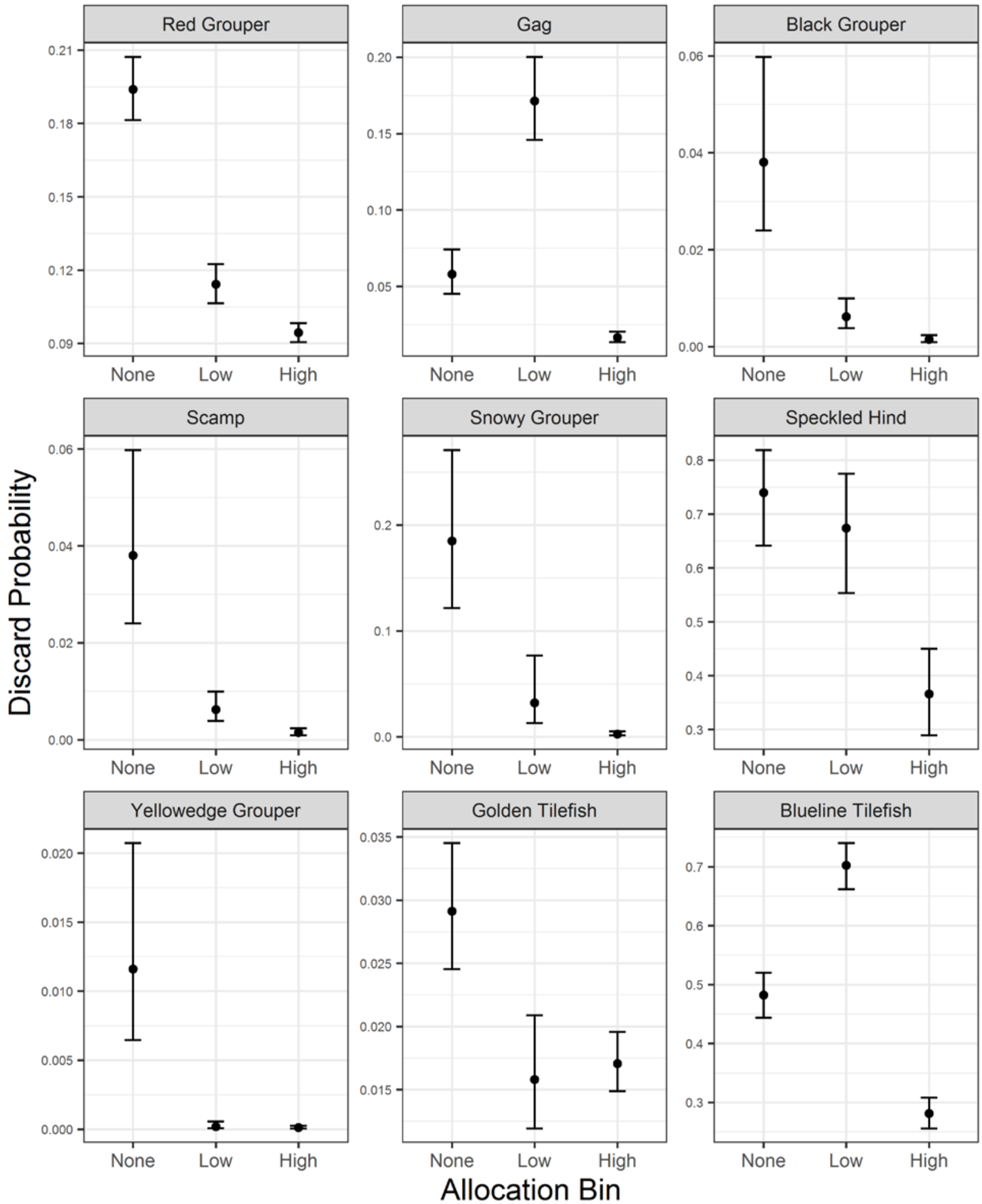

Figure 2. The discard probabilities predicted by the GAM logistic regression model for each allocation bin (none, low, or high) with 95% confidence intervals.

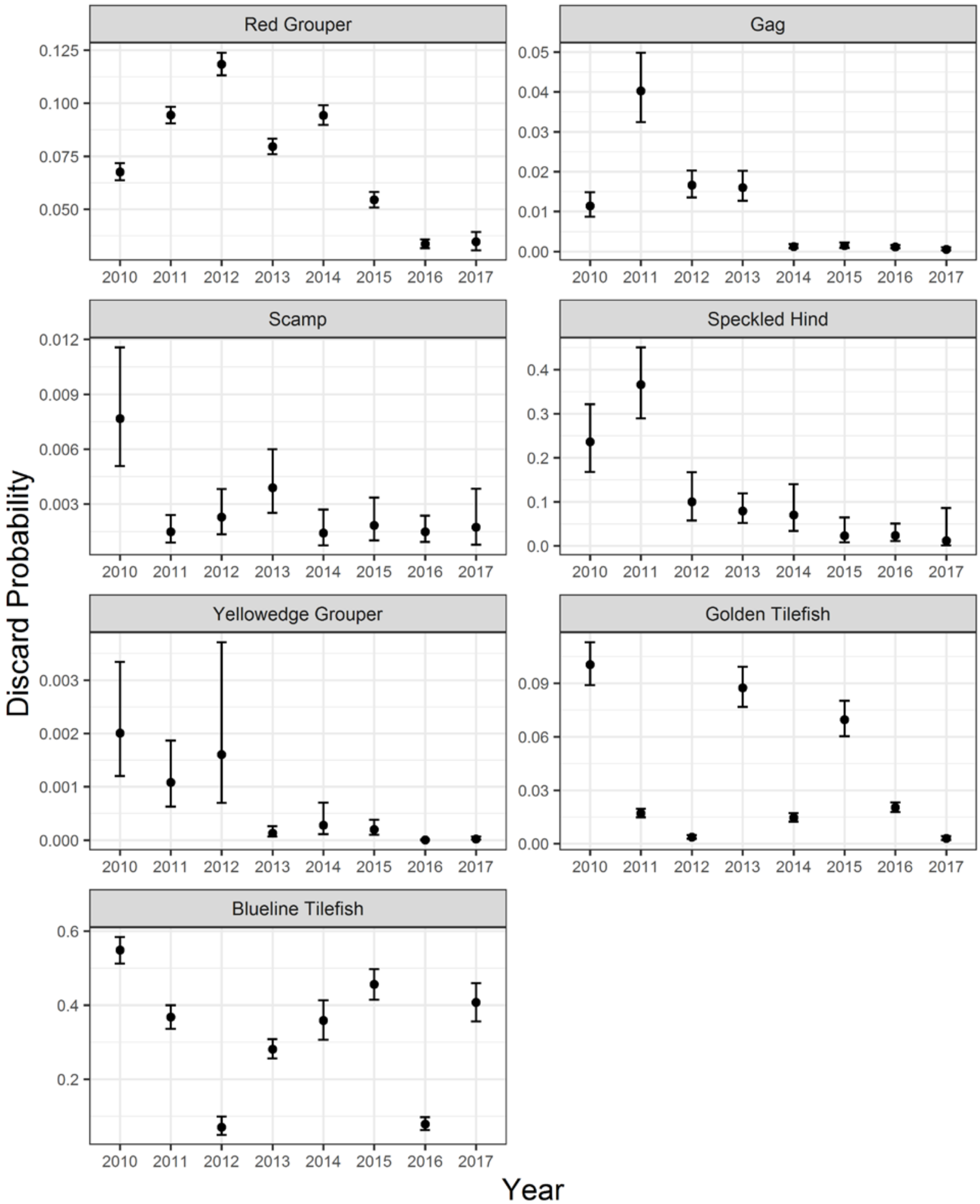

Figure 3. The discard probabilities predicted by the GAM logistic regression model for each year with 95% confidence intervals.

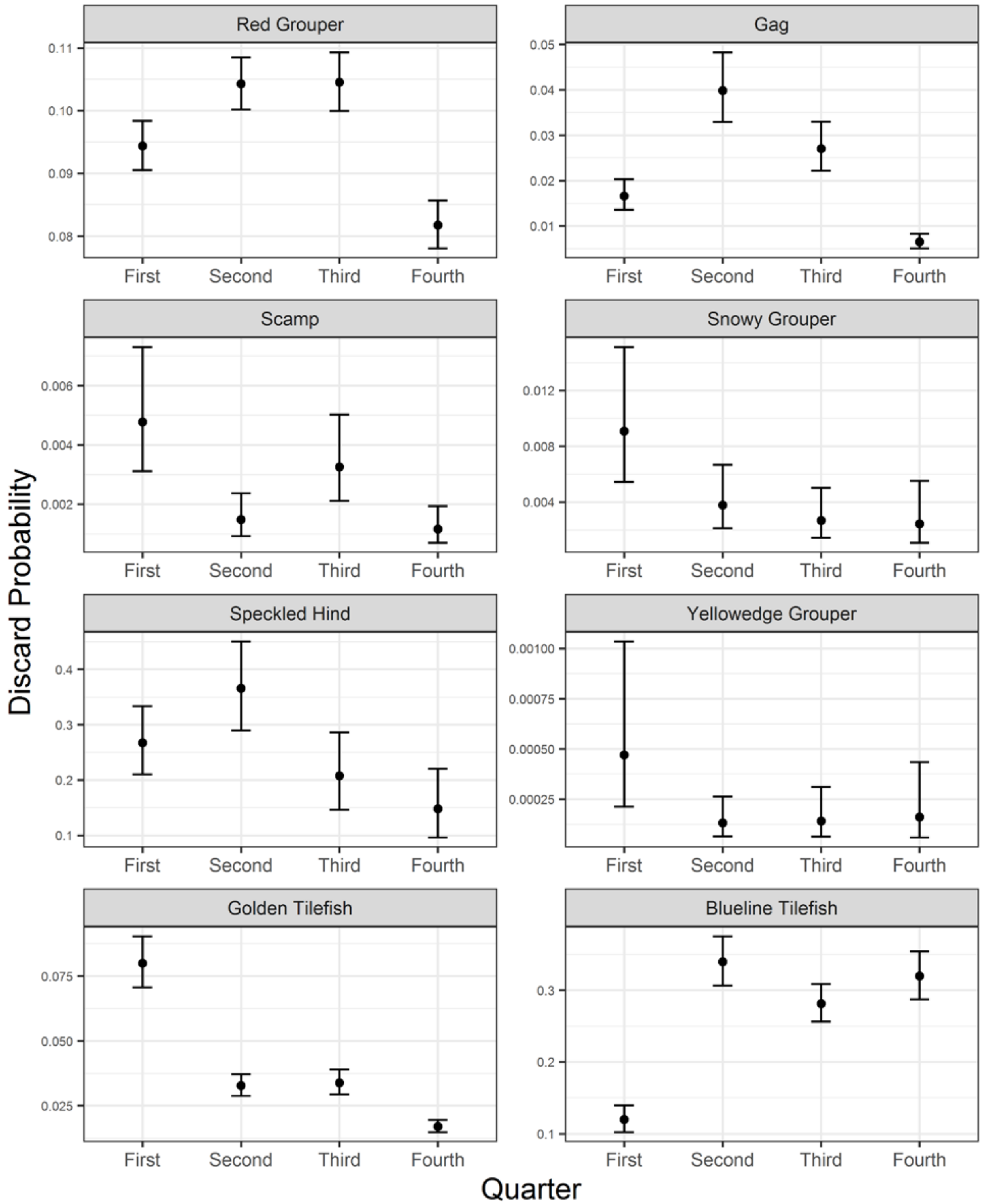

Figure 4. The discard probabilities predicted by the GAM logistic regression model for each calendar year quarter with 95% confidence intervals.

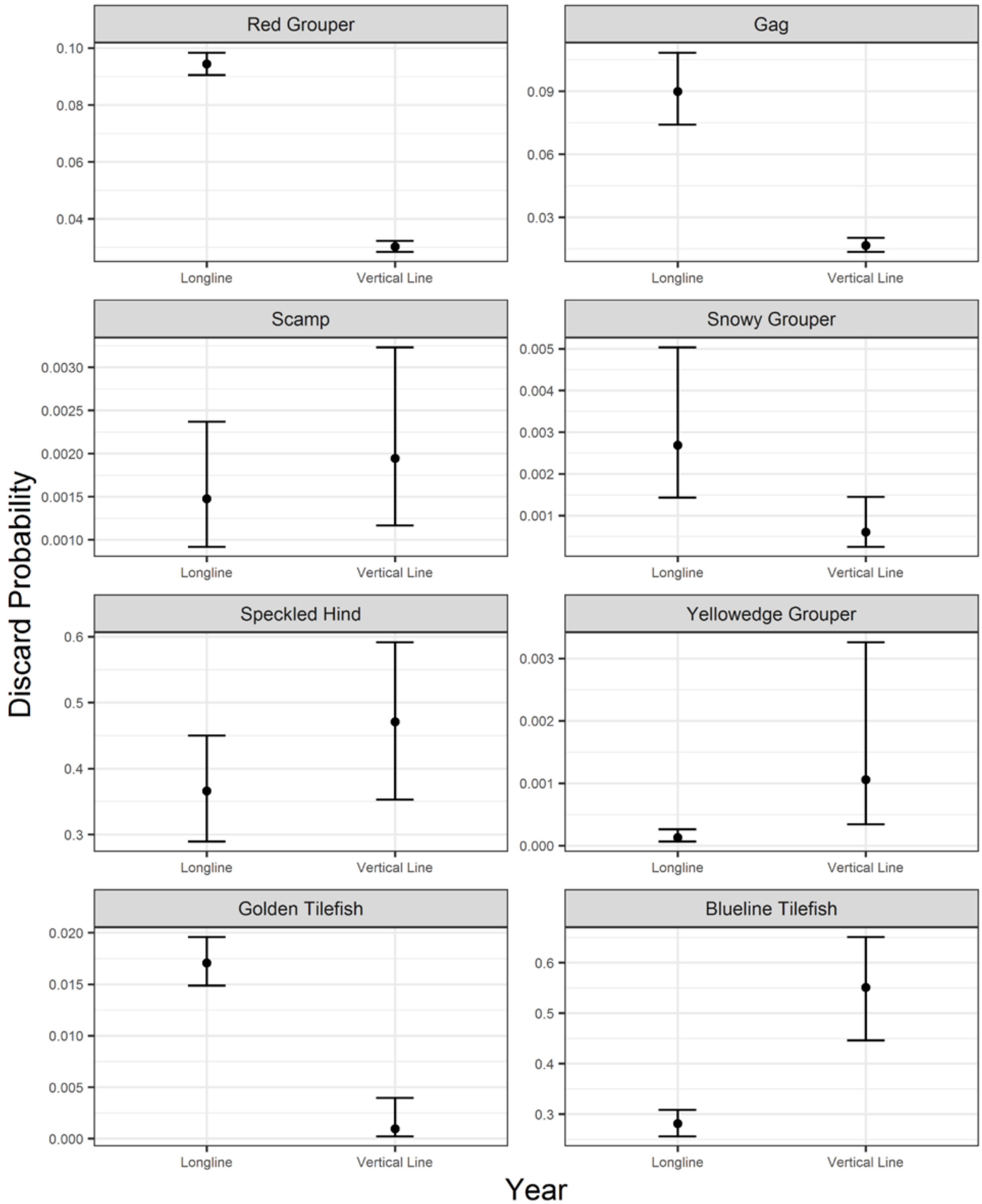

Figure 5. The discard probabilities predicted by the GAM logistic regression model for each gear type with 95% confidence intervals.

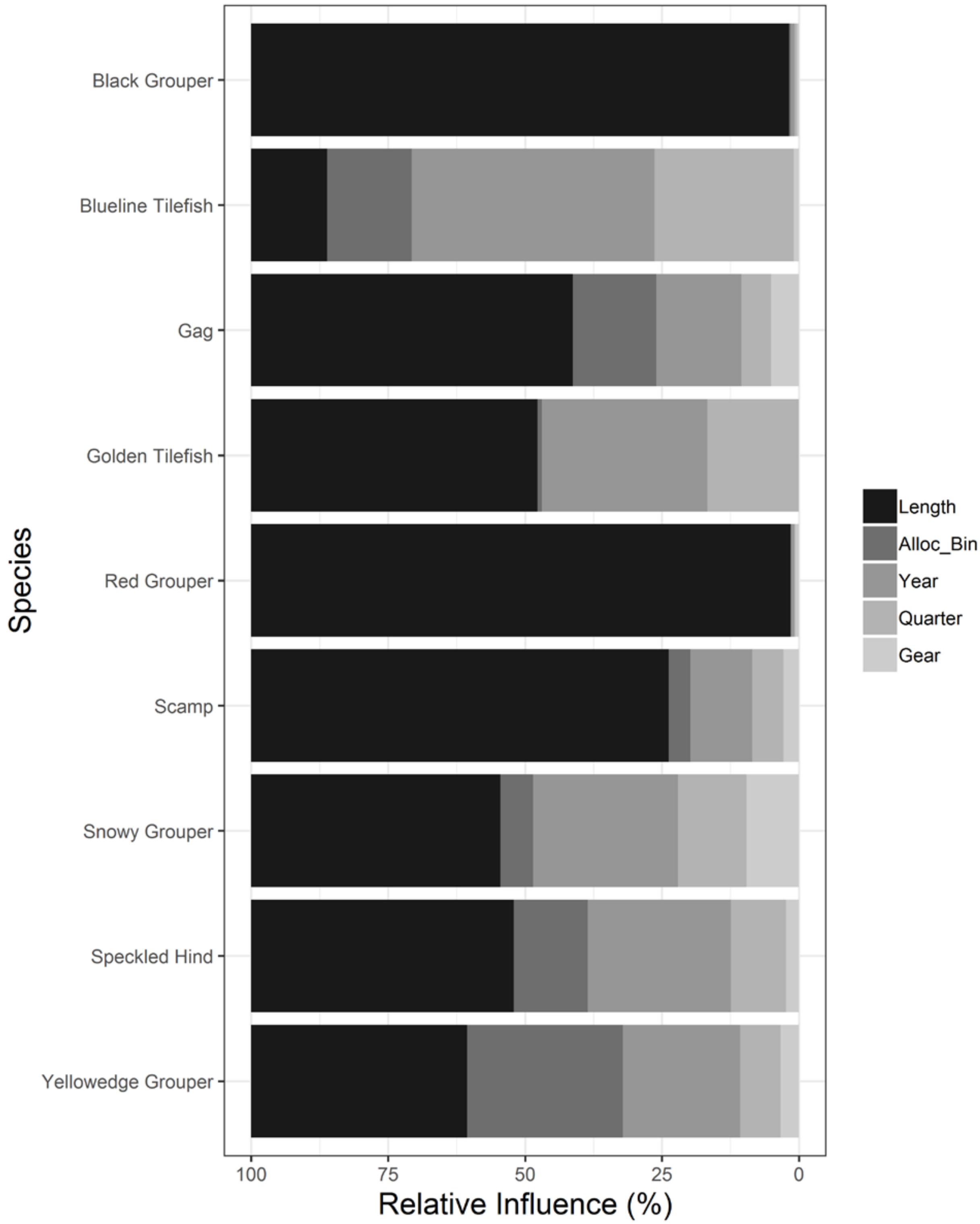

Figure 6. The relative influence for each variable affecting discarding from the boosted logistic regression tree models for nine of the GT-IFQ species.