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ABSTRACT

Fishery observer data collected from June 2006 through December 2015 in the Gulf of Mexico commercial reef fish fishery were examined to determine if any covariates available affected immediate discard mortality for six species: red grouper *Epinephelus morio*, red snapper *Lutjanus campechanus*, vermilion snapper *Rhomboplites aurorubens*, gag grouper *Mycteroperca microlepis*, scamp grouper *Mycteroperca phenax*, and speckled hind *Epinephelus drummondhayi*. Using logistic regression models, this study predicted immediate discard mortality was positively correlated with increased depths, seasons associated with warmer water temperatures, and external evidence of barotrauma. Additionally, bottom longline gear increased the predicted probability of immediate mortality compared to vertical line gear for all species except vermilion snapper. Air bladder venting significantly decreased the predicted probability of immediate mortality for all species except speckled hind. Future research incorporating tag-recapture data into the current observer program for the commercial reef fish fishery is vital to assess if condition assessment at release can be relied on as an accurate proxy for long-term survival. This research provides information that managers could potentially use to make more informed decisions when implementing measures such as changes to existing size limits, venting requirements, and seasonal, area, or gear restrictions intended to reduce unwanted discard mortality.

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1. Introduction

The Gulf of Mexico (Gulf) commercial reef fish fishery is a multi-species fishery primarily targeting groupers (*Epinephelus* sp. and *Mycteroperca* sp.) and snappers (*Lutjanus* sp. and *Rhomboplites* sp.) using two primary gear types, bottom longline and vertical line (handline or bandit). Some of the management options, such as size limits, area closures, and species-specific quota systems, result in fish discarded at-sea in depths correlated with immediate mortality (Bartholomew and Bohnsack, 2005; Gitschlag and Renaud, 1994; Render and Wilson, 1994; Rudershausen et al., 2007; Wilson and Burns, 1996). Grouper and snapper species are physoclistous, meaning they lack a duct leading from the swim bladder to the alimentary canal, making it difficult to quantify discard mortality due to internal injuries potentially not visible at release, e.g. ruptured swim bladder. Additionally, discard mortality rates can be affected by a number of different stressors, such as hooking trauma, barotrauma, handling time, and temperature (Campbell et al., 2014; Curtis et al., 2015; Jarvis and Lowe, 2008). The reduction of catch-and-release mortality rates are an important consideration for fishery managers due to the overexploitation of many stocks. In 2008, Gulf reef fish fishery managers enacted a rule requiring fishermen targeting reef fish to use circle hooks to reduce potentially fatal hook injuries sustained during capture (GMFMC, 2007). At the beginning of 2008, fishermen were required to use a venting tool on swim bladders for released reef fish captures to reduce the effects of barotrauma; however, the venting requirement was rescinded in 2013 due to questions regarding its effectiveness (GMFMC, 2013).

Multiple studies have attempted to quantify long-term survival rates using tag-recapture or other methods such as acoustic telemetry (Curtis et al., 2015; Patterson et al., 2002; Rudershausen et al., 2014; Sauls, 2014). Long-term or delayed discard mortality studies typically include covariates of interest when fitting logistic, proportional hazards regression, or relative risk models to determine their effect on mortality. Using acoustic telemetry (Curtis et al., 2015) and a meta-analysis (Campbell et al., 2014), research has reported reduced mortality rates for red snapper *Lutjanus campechanus* when captured at shallower depths and in seasons associated with cooler water temperatures. Campbell et al. (2014) evaluated the effects of venting the swim bladder of red snapper, and predicted that venting decreased immediate mortality compared to not venting, but increased delayed mortality. Sauls

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(2014), using tag-recapture to estimate long-term mortality for gag grouper *Mycteroperca microlepis*, determined venting was associated with increased mortality, but noted the increased mortality may have been affected by other confounding factors besides venting. For example, Sauls (2014) reported vented gag groupers were typically both larger and caught at greater depths than non-vented fish. In both studies, it was stressed that other factors besides venting, e.g. increased handling time, may affect mortality.

Similar to other studies, the National Marine Fisheries Service (NMFS) Southeast Fisheries Science Center (SEFSC) fishery observer program currently determines immediate discard mortality through surface observations of individual fish after discard (Patterson et al., 2002; Stephen and Harris, 2010). Short-term survival is assumed if the fish rapidly or slowly is able to descend and immediate mortality is classified when the fish floated on the surface or floated on the surface then slowly descended (not swimming). Although submergence ability as a proxy for mortality is problematic since it does not account for any long-term effects, similar studies have shown that when other factors, such as hook trauma or barotrauma, are included it can be used as a reasonably accurate method for inferring mortality rates (Patterson et al., 2002; Rudershausen et al., 2014). Since the data available from the observer program span a relatively long time series and cover a large geographic area, inferences derived should be more robust than studies with a more limited scope and would be reflective of the actual fishery. Also, given that release conditions are highly variable and fish are subject to a multitude of stressors, the large number of observations available for most of the species of interest allows for an accurate evaluation of the different factors potentially affecting mortality. The purpose of this study was to determine if factors collected by the fishery observer program could be used to predict post-release survival for six commonly captured commercial reef fish species in the Gulf: red grouper *Epinephelus morio*, red snapper, vermilion snapper *Rhomboplites aurorubens*, gag grouper, scamp grouper *Mycteroperca phenax*, and speckled hind *Epinephelus drummondhayi*.

2. Methods

2.1. Reef fish observer program data

In July 2006, the NMFS SEFSC began a mandatory observer program with partial coverage to characterize the commercial reef fish fishery in the Gulf (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 reef fish fishery mandatory program, vessels were randomly selected quarterly each year to carry an observer. 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). Beginning in February 2009, increased observer coverage levels were directed at the bottom longline fishery in the eastern Gulf due to concerns regarding sea turtle interactions. Additionally, in 2011, increased funding allowed enhanced coverage of both the vertical line and bottom longline fisheries through 2014. As a result 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 July 2006 through December 2015 were used for all fisheries management analyses (NMFS, 2016). Only data from bottom longline and vertical line were included as >99% of the number of captures for the fishery occurred with these gear types.

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. For the discarded fish, the alive or dead determination was based on surface observation of individual fish. If the fish rapidly or slowly descended, even with barotraumatic stress indicators, it was recorded as alive. It was considered dead if it floated on the surface or floated on the surface then slowly descended (not swimming). Some fish were recorded with an unknown discarded disposition due to the difficulty in observing discards attributed to poor lighting, high seas, or other factors. In this study, only individual fish that were discarded as either alive or dead were used to examine immediate mortality. Individual fish recorded as dead upon arrival were excluded from the analyses since the study's goal was to examine factors affecting survival of fish post-release.

Onboard reef fish vessels, observers assign a condition of capture for each individual fish based on external indicators of barotrauma. Research has shown that external indicators of barotraumatic stress will likely have an implication for the survival of the discarded fish (Rudershausen et al., 2007; Rudershausen et al., 2014). The condition categories were assigned as follows: normal appearance, everted stomach (protrusion from the buccal cavity), exopthalmia (eyes bulging out of the socket), both everted stomach and exopthalmia, dead on arrival, damaged by predators, and unknown. These condition categories attempt to quantify the level of barotraumatic stress on the fish based on expansion of the swim bladder. The expansion of the swim bladder can force the stomach and/or eyes out of the body cavity. Observers also recorded if the fish was vented (air bladder punctured) prior to release by the vessel; however, no distinction on the quality of the observed technique was recorded. Fishery observers measured fork length to the nearest mm for all species except for scamp grouper which were measured as stretched total length. Bottom depths were recorded in feet using fishing vessel equipment, i.e. typically depth sounders, and for vertical line vessels a fishing depth was estimated by monitoring gear deployment at each fishing site. All depths were converted to meters for the analyses.

2.2. Statistical analyses

For each of the six species, logistic regression models were fit using stepwise backwards selection to determine which covariates affected the proportion of immediate mortality observed. Non-significant ($P > 0.05$) covariates were removed using the likelihood ratio χ^2 *P*-Value to determine significance at each step. The initial model fit to the binary response of immediate mortality (alive or dead) was modeled as;

$$Logit\,(Y_i) = \alpha + \beta Depth_i + \beta Season_i + \beta GearType_i + \beta Length_i + \beta ConditionCategory_i + \beta Vented_i \quad (1)$$

where α is the intercept and β are the estimated model coefficients, depth of capture, astronomical season (e.g. winter is from 21 December through 21 March), gear type (bottom longline or vertical line), length, condition category at capture, and whether vented occurred. For the significant variables remaining in the models, the predicted odd ratios with profile likelihood 95% confidence intervals calculated using the 'confint' function in R were reported. For each final model, the overall χ^2 significance compared to an intercept only model, percent of deviance explained, and area under the receiver operating characteristic curve (AUC) were also reported. The AUC is a measure of overall model predictive accuracy, with 0.5 considered random and 1.0 a perfect fit (Agresti, 2013).

Hosmer-Lemeshow test statistics were used to assess the goodness of fit for each logistic regression model (Agresti, 2013). The Hosmer-Lemshow test sorts the observations (n) in the data set by the estimated probability of success and divides the sorted set into groups (g). The difference in the expected and observed counts

Table 1
Summary information including the total number of observations, proportion with immediate mortality, mean depth and range in m, mean length and range in mm, number captured by each gear type (LL = bottom longline, VL = vertical line), number in each season (S = spring, Su = summer, A = autumn, W = winter), number for each condition categories (N = normal appearance, S = everted stomach, E = exopthalmia, ES = both E and S), and the proportion of each species with air bladders vented prior to release.

Species	Number Observed	Immediate Mortality	Depth Range	Mean Depth	Length Range	Mean Length	Gear Type	Season	Condition Category	Proportion Vented
Red Grouper	141,291	0.24	4.27–124.36	48.15	169–792	411.5	LL-110681 VL-30610	S-41642 Su-36444 A-28193 W-35012	N-40523 S-58926 E-20499 ES-21343	0.84
Red Snapper	34,465	0.24	6.10–285.29	52.56	141–917	461.8	LL-10182 VL-24283	S-8645 Su-9938 A-7612 W-8270	N-19369 S-13751 E-877 ES-468	0.65
Vermilion Snapper	10,202	0.44	18.29–205.44	59.90	106–553	222.6	LL-120 VL-10082	S-3109 Su-3145 A-1855 W-2093	N-9719 S-378 E-93 ES-12	0.34
Gag Grouper	5975	0.08	4.57–149.41	41.71	236–1303	595.1	LL-1947 VL-4028	S-2268 Su-1088 A-877 W-1742	N-3600 S-2158 E-110 ES-107	0.49
Scamp Grouper	636	0.35	12.80–163.07	65.99	211–892	407.7	LL-114 VL-522	S-137 Su-226 A-98 W-175	N-440 S-131 E-51 ES-14	0.59
Specked Hind	482	0.38	42.06–199.34	80.32	241–791	441.3	LL-335 VL-147	S-195 Su-87 A-43 W-157	N-127 S-215 E- 45 ES-95	0.93

for all groups are summed and compared to the χ^2_{g-2} to obtain the test statistic with $P < 0.05$ indicating a lack of fit. However, it has been shown that the Hosmer-Lemshow test has the undesirable effect of increased power with large data sets as with any statistical test. Therefore, this study followed the guidelines proposed by Paul et al. (2013) for models with observations >1000 in the logistic regression model. The study proposed changing g for samples sizes $1000 \leq n \leq 25{,}000$ where m is the number of successes, e.g. immediate discard mortality, using the equation:

$$g = max\left(10, min\left\{\frac{m}{2}, \frac{n-m}{2}, 2+8\left(\frac{n}{1000}\right)^2\right\}\right) \quad (2)$$

For sample sizes >25,000 no clear recommendation is given, but it was suggested that 1000 random samples could be drawn and that the Hosmer-Lemeshow test statistic be calculated on the reduced model using the trimmed data set. A novel extension of the recommendation for large data sets was performed using 1000 iterations of the random samples to obtain the suggested test statistic on the trimmed data set. The resulting mean test statistic from the 1000 P-values was reported.

A final hierarchical logistic regression model was fit to compare differences among species for each covariate. The same model as previous was fit, but an interaction term was added between each covariate and the different species to differentiate their predicted effect on mortality. The resulting model was:

$$Logit\,(Y_i) = \alpha + \beta Depth_i * Species + \beta Season_i * Species$$
$$+\beta GearType_i * Species + \beta Length_i * Species \quad (3)$$
$$+\beta ConditionCode_i * Species + \beta Vented_i * Species$$

The predicted immediate mortality probability for each species with 95% confidence interval were then plotted and visually examined for patterns in effect among species. All predicted immediate mortality probabilities use the median for continuous variables and the most common factor for categorical variables of the aggregated data. All analyses in this research were performed using R statistical software (version 3.3.0; R Core Team 2016). Finally, R code is given for calculating the Hosmer-Lemeshow test statistic, as previously detailed based on the number of observations, and plotting the expected versus observed values for the number of groups suggested (see Supplementary material).

3. Results

A wide range of observations was available for the six species of interest in the study. The greatest number of discarded captures with a disposition of alive or dead was recorded for red grouper with 141,291 compared to the least amount observed for speckled hind with 482 (Table 1). The proportion of immediate discard mortality for each species ranged from a low of 0.08 for gag grouper to a high of 0.44 for vermilion snapper with proportions of 0.24 for both red grouper and red snapper. Depths of capture ranged from a minimum of 4 m for red grouper to a maximum of 285 m for red snapper. Depths of capture mostly overlapped between each species, with speckled hind as the only exception never being captured in waters <42 m (see Figure A.1). Although all species had observations recorded for each categorical variable level, some levels had limited observations available, such as only 43 observations for speckled hind in autumn. Furthermore, quasi-complete separation (perfect prediction) existed for scamp grouper because all the fish recorded with both an everted stomach and exopthalmia resulted in immediate discard mortality. The proportion of air bladder venting varied among species with the highest values recorded for speckled hind and red grouper. The lowest proportions of air bladder venting were reported for vermilion snapper and gag grouper (both < 0.5).

Individual logistic regression models predicted that immediate discard mortality was significantly and positively correlated with increased depths for all six species (Table 2). Bottom longline gear increased the predicted odds of immediate mortality compared to vertical line gear for all species except vermilion snapper. For all species except scamp grouper, seasonal changes were significant predictors of mortality with increased odds during the typically warmest seasons of summer and autumn. Conversely, the winter season mostly had the lowest predicted odds of mortality follow-

Table 2
Final logistic regression model odds ratios with profile likelihood 95% confidence intervals for the variables depth (m), length (mm), gear type bottom longline (LL) compared to vertical line, each season compared to autumn, condition categories (S = everted stomach, E = exophthalmia, ES = both E and S) compared to normal appearance, and whether the fish was vented prior to release compared to not vented.

Species	Depth	Length	Gear Type Bottom LL	Season Spring	Season Summer	Season Winter	Condition Category S	Condition Cat. E	Condition Cat. ES	Vented True
Red Grouper	1.01 (1.01,1.02)	1.00 (1.00,1.00)	2.41 (2.31,2.51)	0.64 (0.62,0.67)	0.90 (0.86,0.94)	0.83 (0.79,0.86)	1.00 (0.97,1.04)	3.01 (2.89,3.14)	3.22 (3.09,3.36)	0.43 (0.41,0.45)
Red Snapper	1.03 (1.02,1.03)	1.00 (1.00,1.00)	1.02 (0.95,1.11)	0.69 (0.63,0.74)	1.06 (0.98,1.14)	0.54 (0.5,0.59)	1.71 (1.61,1.81)	4.49 (3.86,5.22)	7.30 (5.89,9.05)	0.50 (0.47,0.53)
Vermilion Snapper	1.03 (1.03,1.03)	0.99 (0.99,1)	–	0.63 (0.56,0.72)	0.88 (0.78,1.00)	0.53 (0.47,0.61)	–	–	–	0.79 (0.72,0.87)
Gag Grouper	1.02 (1.02,1.03)	1.00 (1.00,1.00)	5.48 (3.74,8.03)	1.45 (0.96,2.19)	2.05 (1.33,3.17)	0.59 (0.37,0.94)	1.51 (1.18,1.94)	4.21 (2.43,7.30)	4.81 (2.91,7.97)	0.38 (0.27,0.53)
Scamp Grouper	1.04 (1.03,1.05)	–	2.95 (1.75,4.98)	–	–	–	2.04 (1.2,3.44)	4.18 (1.82,9.62)	18.34 (0,Infinity)	0.45 (0.27,0.77)
Speckled Hind	1.03 (1.01,1.04)	–	1.81 (1.03,3.17)	0.32 (0.15,0.69)	0.70 (0.31,1.58)	0.34 (0.16,0.72)	0.89 (0.52,1.50)	2.73 (1.29,5.79)	3.41 (1.86,6.27)	–

ing the relationship of decreased mortality occurring in seasons associated with cooler water temperatures. External evidence of barotrauma was consistently associated with higher predicted odds of immediate mortality, with exopthalmia a more severe stressor than an everted stomach. A combination of exopthalmia and an everted stomach resulted in the greatest predicted odds for all species except vermilion snapper. Air bladder venting significantly decreased the predicted probability of immediate mortality for each species, except speckled hind for which venting was discovered to be a non-significant predictor. For red snapper, red grouper, gag grouper, and scamp grouper venting the air bladder reduced the probability of immediate mortality by ≥0.5.

For the individual logistic regression models, the percentage of deviance explained ranged from a minimum of 8.8% for red grouper to a maximum of 29.9% for scamp grouper (Table 3). All the AUC values were >0.7 indicating good model predictive accuracy, with the largest values observed for gag (0.88) and scamp grouper (0.85). The modified Hosmer–Lemeshow goodness-of-fit test statistic indicated acceptable fits for each species, with vermilion snapper as the only exception. The lack of fit was evident when plots of the expected versus observed values were compared, with more variance for groups of vermilion snapper compared to other species (see Figure A.2).

Comparing differences in predicted immediate discard mortality among the species when controlling for other covariates, similar trends to each individual model were evident. For example, bottom longline gear consistently had higher predicted immediate mortality compared to vertical line for each species, with the greatest predicted increase for scamp grouper (Fig. 1). Higher mortality was predicted for the seasons associated with warmer water temperatures and external evidence of barotrauma, with a combination of exopthalmia and stomach eversion resulting in the largest probabilities. Air bladder venting had a positive effect, decreasing predicted mortality for all six species. The effect of depth on predicted immediate mortality was most evident for scamp grouper relative to other species, with 50% mortality occurring near 60 m (Fig. 2). Controlling for other covariates, red and gag grouper had the least predicted increase in mortality with depth, with estimated probabilities of death > 0.25 only occurring near 100 m. Length was a species-specific, highly variable predictor of immediate mortality (Fig. 3). Red and gag grouper had increased mortality associated with larger fish, contrary to the snapper species which had higher mortality predicted for smaller sized individuals. Length for scamp grouper and specked hind had no or minimal effect on immediate mortality with broad confidence bands containing any predicted difference in size.

4. Discussion

This study provides evidence that multiple factors are influencing immediate discard mortality rates in the Gulf commercial reef fish fishery. The predicted rates are similar to other studies of the same or similar species in the region. Using hook-and-line sampling off North Carolina, Overton et al. (2008) determined the highest post-release immediate mortality occurred for scamp groupers (43.8%) and the lowest for gag groupers (13.3%). Rudershausen et al. (2007) also reported the highest observed immediate mortality for scamp grouper (23%) and the lowest for gag grouper (0%) from data collected on commercial vessels off North Carolina. Similar to Overton et al. (2008) and Rudershausen et al. (2007), gag grouper here had the lowest and scamp grouper the highest predicted mortality for each variable examined (Figs. 1–3). When Rudershausen et al. (2007) included delayed mortality using Monte Carlo simulation with barotrauma and hooking location to calculate estimates, both scamp and gag grouper had similar high mortal-

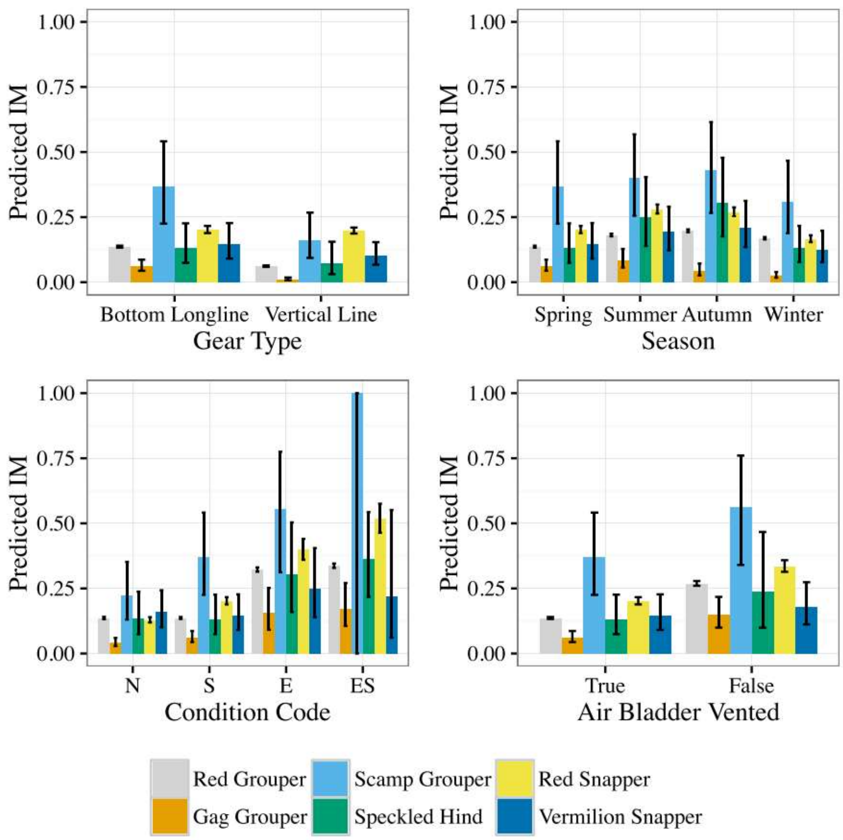

Fig. 1. The immediate mortality (IM) probabilities predicted by the logistic regression model comparing each species by gear type, season, condition category (N = normal, S = everted stomach, E = exophthalmia, ES = both E and S), and whether the fish was vented prior to release with 95% confidence intervals.

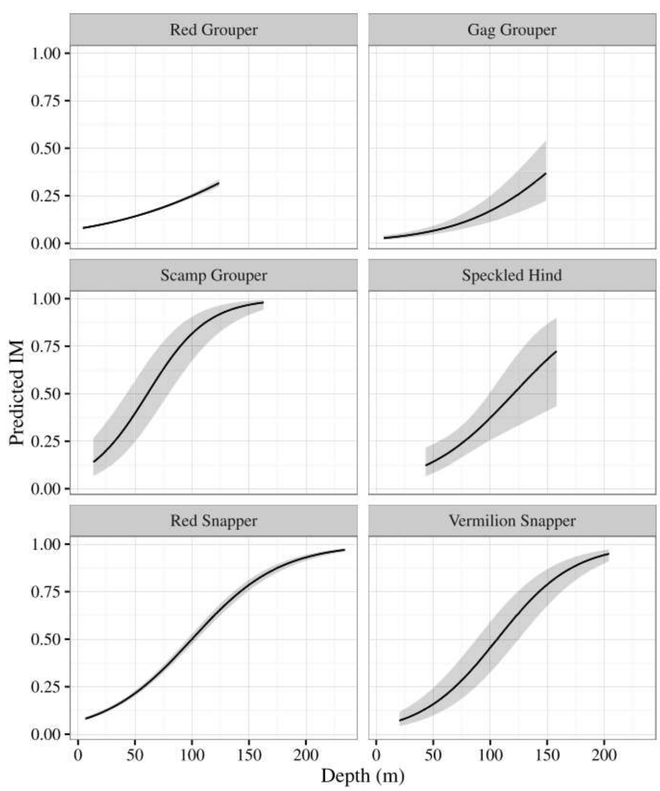

Fig. 2. The immediate mortality (IM) probabilities predicted by the logistic regression model for each species by depth with 95% confidence intervals.

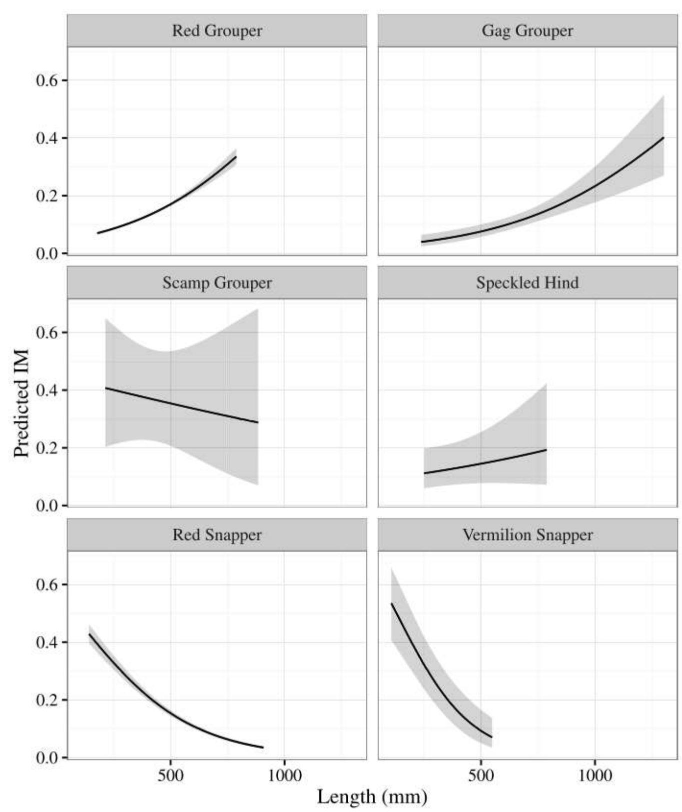

Fig. 3. The immediate mortality (IM) probabilities predicted by the logistic regression model for each species by length with 95% confidence intervals.

Table 3
Final logistic regression model variable significance using the likelihood ratio χ^2 *P*-value, χ^2 model significance, percent of deviance explained, the Hosmer-Lemeshow goodness-of-fit test statistic, and area under the receiver operating characteristic curve (AUC).

Species	Depth	Length	Gear Type	Season	Condition Category	Vented	χ^2 Significance	Deviance Explained	Hosmer-Lemeshow	AUC
Red Grouper	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	8.8%	0.45	0.71
Red Snapper	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	9.9%	0.26	0.71
Vermilion Snapper	<0.01	<0.01	–	<0.01	–	<0.01	<0.01	9.3%	<0.01	0.70
Gag Grouper	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	27.5%	0.09	0.88
Scamp Grouper	<0.01	–	<0.01	–	<0.01	<0.01	<0.01	29.9%	0.17	0.85
Speckled Hind	<0.01	–	0.01	0.01	<0.01	–	<0.01	9.6%	0.95	0.70

ity rates, 35% and 33% respectively. One potential reason for the discrepancy in gag grouper mortality between studies is the differences in trauma associated with J-hooks. The discards reported by Rudershausen et al. (2007) were captured exclusively with J-hooks. Overton et al. (2008) reported a random mix of circle and J-hooks, and Gulf commercial fishermen almost exclusively use circle hooks since the 2008 mandate (Scott-Denton et al., 2011; Scott-Denton and Williams, 2013).

Stephen and Harris (2010) quantifying immediate mortality rates, using a similar methodology as this study, revealed consistently higher immediate release mortality for some of the same species. Stephen and Harris (2010) sampling commercial fishing vessels off South Carolina reported that the majority of species had discard mortality rates > 0.8, however, limited sample sizes were reported for many of released species, with five species represented by only one discarded individual. The most common species observed by Stephen and Harris (2010) was vermilion snapper with 707 discards. Vermilion snapper observed by Stephen and Harris (2010) had an immediate predicted mortality of 0.48 consistent with the 0.44 proportion reported here. Stephen and Harris (2010) also described a similar relationship between length and mortality for vermilion snapper observed in this research, i.e., significantly increased mortality for the smaller sized fish (Fig. 3). Similarly, Patterson et al. (2002) predicted decreased survival for smaller sized red snapper, also consistent with the results of this study.

The seasonal effect on immediate mortality, with increased mortality occurring during the warmer periods, is consistent with other studies (Campbell et al., 2014; Curtis et al., 2015; Jarvis and Lowe, 2008). Regulations enacted in 2010 to reduce sea turtle interactions with bottom longline gear may have also unintentionally reduced commercial discard mortality rates for red grouper in the Gulf. The regulations prohibited bottom longline gear primarily used to target red grouper shoreward of the 35-fm contour from June through August (typically some of the warmest months) causing either a temporal or spatial shift in effort or vessels to switch to an alternate gear type during that period (GMFMC, 2010). Even a moderate shift in effort towards seasons with lower water temperatures could have had a significant effect since a large proportion of discards has been observed in the commercial red grouper fishery. Based on observer coverage from 2006 to 2013, overall discard rates between 32 and 54% were reported for both gear types combined and were higher in the bottom longline fishery.

Similar to other studies, depth was inversely related to survival for all species; however, the magnitude of the predicted effect varied by species (Fig. 2). Both snapper species and speckled hind had an immediate mortality of 0.5 predicted near 100 m, considerably higher than both red and gag groupers which were always <0.5. However, the prediction range was <150 m for both grouper species. The lower predicted probabilities for red and gag grouper by depth may have been confounded by length since each species had higher probabilities of mortality predicted for larger sized individuals, which typically occur in deeper waters (Fig. 3). The lower predicted probabilities of mortality for smaller sized red and gag groupers support the minimum size restrictions currently used in the fishery since smaller sizes does not increase the removal from the population. Conversely, relatively high mortalities (>0.25) of smaller sized individuals were predicted for both red and vermilion snappers, indicating current minimum size regulations may not be as effective in protecting stocks.

Future research incorporating tag-recapture with the observer program data for the commercial reef fish fishery is vital to assess if surface estimates of mortality can be relied on as an accurate proxy for long-term survival. Although Patterson et al. (2002) and Rudershausen et al. (2014) concluded submergence after release with condition assessment, e.g. hook trauma or barotrauma, could provide accurate estimates of discard survival, no studies confirming these results could be found for some species in the current research. No long-term discard mortality information could be located for reef fish species captured using bottom longline gear. Comparing gear types using observer data from 2006 to 2013, red grouper had less external barotrauma when captured with bottom longline versus vertical line gear for comparable depth bins, but overall higher immediate mortality proportions for each 10 m depth bin. Based on fishery observer coverage from 2010 to 2013 in the bottom longline fishery, the mean hook soak time was 116 min (NMFS, unpublished data). Assuming a relatively short capture time, a large number of bottom longline captures may be hooked for extended durations creating additional stressors. These stressors, such as exhaustion, not related to barotrauma may be causing the increased immediate mortality rates observed.

Red grouper and speckled hind were vented at higher proportions than the other species examined (Table 1). Based on informal discussions with observers post-cruise, the differences in the proportion being vented may be occurring because venting fish with stomach eversion is perceived as more beneficial than venting fish with a normal appearance. The most common condition of capture category recorded for red grouper and speckled hind was stomach eversion, compared to the other species which all had a normal appearance as the most frequent category. The mechanism causing stomach eversion on a higher percentage of captures for these two species is not definitively known, but could be linked to physiological differences. Sauls (2014) and Campbell et al. (2014) revealed that the long-term effectiveness of venting in reducing mortality remains unknown due to the confounding influences of increased handling time or internal injuries sustained through improper techniques. Although venting significantly lowered the predicted immediate mortality for most species in this research, a tag-recapture program is necessary to determine if the benefits extend beyond the short-term. Both studies suggest future research is needed to compare venting to descending devices (used to aid recompression) for determining specific mechanisms affecting survival.

Accurate estimates of release mortality rates are critical for fishery managers attempting to maximize yield. By incorporating a tag-recapture program and investigating the effects of extended hooked times, the current observer program data can increase its accuracy in estimating release mortality rates. In turn, this research increases our understanding of release mortality in the Gulf commercial reef fish fishery by predicting relationships using a relatively large data set with broad temporal and spatial coverage. Using this information, managers can focus future research efforts and regulations on those most likely to reduce unwanted discard mortality, likely increasing the long-term sustainability of the reef fish fishery.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2016.12.018.

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