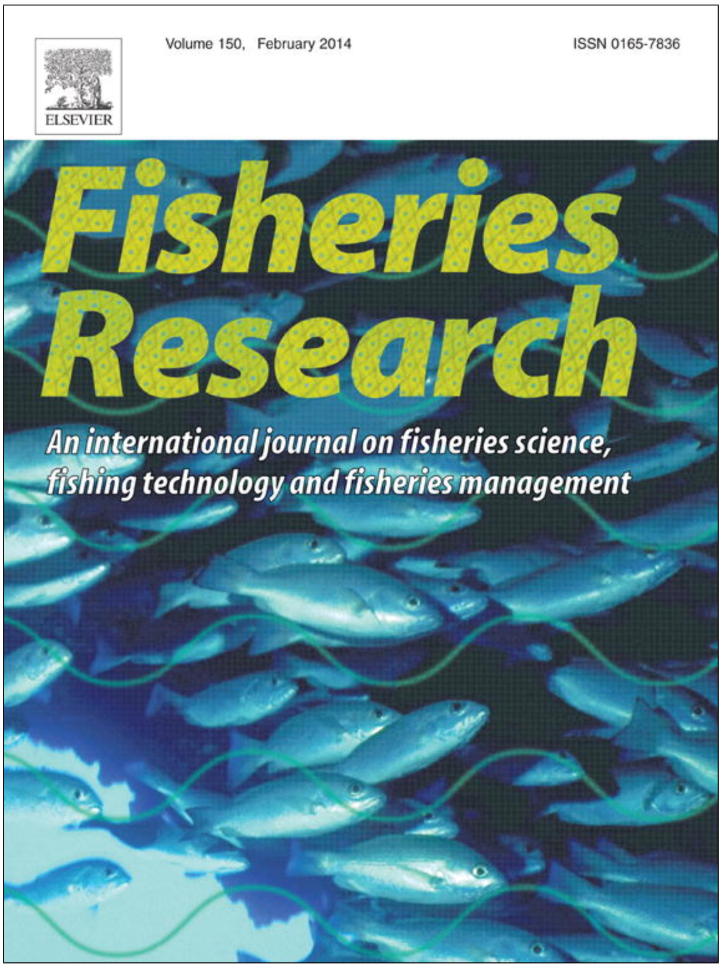
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Relative survival of gags *Mycteroperca microlepis* released within a recreational hook-and-line fishery: Application of the Cox Regression Model to control for heterogeneity in a large-scale mark-recapture study

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ABSTRACT

From June 2009 through December 2012 fishery observers were placed on charter and headboat vessels operating in the Gulf of Mexico to directly observe reef fishes as they were caught by recreational anglers fishing with hook-and-line gear. The objective of this study was to relate injuries and impairments measured directly from gags *Mycteroperca microlepis* caught and released within the recreational fishery to subsequent mark-recapture rates. Due to the large spatial and temporal scales of the study design, it could not be assumed that encounter probabilities were equal for all individual tagged fish in the population. Also, changes in fishing effort following the Deepwater Horizon oil spill during 2010 in the Gulf of Mexico and drastically reduced recreational harvest seasons for gag during 2011 and 2012 were unanticipated during the design of this study. Therefore, it was necessary to control for potential covariates on encounter and recapture rates for gags tagged in different regions, different years, and different times of year. This analysis demonstrates the utility of the Cox regression proportional hazards model in comparing relative survival among gags released in various conditions while controlling for potential covariates on both the occurrence and timing of recapture events. A total of 3954 gags were observed in this study, and the majority (77.26%) were released in good condition (condition category 1), defined as fish that immediately submerged without assistance from venting and had not suffered internal injuries from embedded hooks or visible damage to the gills. However, compared to gags caught in shallower depths, a greater proportion of gags caught and released from depths deeper than 30 m were in fair or poor condition. Relative survival was significantly reduced (alpha <0.05) for gags released in fair and poor condition after controlling for variable mark-recapture rates among regions and across months and years when tagged fish were initially captured and released. Gags released within the recreational fishery in fair and poor condition were only 66.4% (95% C.I. 46.9–94.0%) and 50.6% (26.2–97.8%) as likely to be recaptured, respectively, as gags released in good condition. Overall discard mortality was calculated for gags released in all condition categories at 10 m depth intervals. There was a significant linear increase in estimated mortality from less than 15% (range of uncertainty, 0.1–25.2%) in shallow depths to 30 m, to 35.6% (5.6–55.7%) at depths greater than 70 m ($p < 0.001$, $R^2 = 0.917$)

1. Introduction

In the Gulf of Mexico, gag *Mycteroperca microlepis* are highly sought for their recreational value, particularly in nearshore areas along the shallow west Florida continental shelf, where the species is abundant. The Gulf region supports some of the largest recreational fisheries in the United States, with the greatest concentration of effort along the west coast of Florida (Hanson and Sauls, 2011). For some highly targeted species in the region, total removals from recreational fisheries can exceed those from commercial fisheries (Coleman et al., 2004). Quantifying fishery removals attributed to mortality of regulatory discards has become an important data need for regional stock assessment models. Recreational fisheries are currently managed with an allocation of 61% of the total allowed catch for gag (GMFMC, 2008), which includes estimated removals attributed to mortality of discarded fish. In 2011–2012, recreational anglers fishing from the west coast of Florida caught an estimated 1 million gags annually (including

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harvested and released fish), down from 2.2 to 4.5 million gags in previous years (personal communication, National Marine Fisheries Service, Fisheries Statistics Division). Recreational harvest is regulated through a combination of minimum size limits, daily bag limits, and harvest seasons that have become increasingly restrictive in recent years. Prior to 2011, recreational harvest was closed during February and March to protect gag spawning aggregations. However, in 2009 the gag stock in the Gulf of Mexico was classified as overfished and undergoing overfishing, and since 2011 recreational harvest has been closed for a majority of months to allow the stock to recover. Consequently, approximately 90% of gags caught by recreational anglers in recent years were released as discards.

A field of study has emerged in recent decades to elucidate factors that influence survival of regulatory discards, including exposures to barotrauma, hook injuries, and variable handling and release techniques (reviews in: Bartholomew and Bohnsack, 2005; Cooke and Suski, 2004; Cooke and Schramm, 2007; Rummer, 2007; Wilde, 2009). Shortcomings of available studies are that many have focused on isolating the effects of a single factor, such as hook injury or barotrauma, often under experimental conditions, and results vary. In addition, many studies have not measured latent mortality and have provided only a partial measure of discard mortality. Some experimental studies have evaluated effects of exposure to multiple factors by retaining fish in cages to quantify immediate and short-term mortalities (Diamond and Campbell, 2009; St. John and Syers, 2005), and models for discard mortality that attempt to account for multiple factors have also begun to emerge (Rummer, 2007). Recent studies indicate that seasonal differences in water temperature at the surface and beneath the thermocline may also have an important influence on the condition of fish retrieved from depth (Diamond and Campbell, 2009), and more year-round studies are needed to fully assess seasonal effects of fishing on survival.

There is a growing need for methods that relate capture and handling practices measured in situ (i.e. within fisheries) to subsequent survival of released fish. Such methods are necessary to assess the true benefits of harvest control measures that may also result in increased regulatory discards and to quantify actual reductions in discard mortalities attributed to conservation measures, such as the use of circle hooks (Coggins et al., 2007; Cooke and Schramm, 2007; Sauls and Ayala, 2012). Conventional tagging studies have been used extensively to estimate survival in open populations (Pine et al., 2003). The advantages of mark-recapture studies to evaluate catch-and-release survival are that they measure survival under natural conditions, potential interactions between multiple stressors are measured intrinsically, latent mortality is included in survival estimates, and any potential increased mortality due to predation of impaired fish is not excluded, as it is in cage and laboratory studies. Models developed for tag-recapture data that were designed to estimate population parameters, however, are not useful for evaluating relationships between survival and explanatory variables (Burnham et al., 1987). Furthermore, many tag-recapture models require that individuals be tagged and recovered during discrete sampling events, which is not always possible, particularly in in situ studies. Estimates of survival derived from tag-recapture models were once thought to be robust to the assumption that all tagged fish within a study shared equal probabilities for recapture, but it has now been shown that variable encounter probabilities can introduce substantial bias in parameter estimates in tag-recapture models (Pledger et al., 2003).

Hueter et al. (2006) described a tag-recapture model that assumed equal encounter probabilities and equal survival rates following a recovery period for sharks tagged and released from gill nets. Each tagged fish was assigned to one of several treatment groups based on a measured risk for reduced survival, which for that study was based on the amount of time required to revive sharks caught during release from the gear. The ratios of fish tagged and recaptured among treatment groups was used to calculate relative survival (S), as

$$S = \frac{R_e}{R_u}, \tag{1}$$

where R_e is the ratio of recaptured fish to tagged fish within an exposed (e) treatment group (sharks that required variable lengths of revival time) and R_u is the ratio of recaptured fish to tagged fish within a relatively unexposed (u) treatment group (sharks that required no revival time). The authors demonstrated that this ratio is derived from a logistic model that predicts the proportions of recaptured fish from the exposed and unexposed groups. Eq. (1) assumes that all tagged fish have approximately the same catchability and are subject to the same amount of fishing effort; therefore, the ratio of recapture rates among the two groups is determined solely by the abundance of tagged fish in each group that survived following catch-and-release. The logistic model may also be generalized to include covariates that influence the encounter probability for individual tagged fish.

Survival analysis, also called time-to-event analysis, is more sophisticated, in that it evaluates both the occurrence and timing of recapture events for individual tagged fish. Survival in this type of analysis refers to the length of time an individual is observed in a study before a discrete event occurs. The method has been applied widely in biomedical research to measure, for example, the influence of variable exposure levels on time until death or the onset of disease. Pollock et al. (1989) described the use of survival analysis for testing hypotheses regarding the influence of condition measures on survival of individual animals. Hoffman and Skalski (1995) also demonstrate the utility of survival analysis for handling complex study designs that include multiple tagging groups defined, for example, by different tagging locations, genders, and treatments. Survival analysis accommodates staggered entry times, so long as entry times vary randomly across individuals in the study, and instantaneous recovery times for marked individuals (Hoffman and Skalski, 1995; Pollock et al., 1989). Survival analysis also does not require that the fate of every individual be known. Provided that, for any individual in the study, time until first recapture and time at large without recapture are independent, then individuals that are not reported as recaptured may be included in the analysis as right-censored observations, where the observation time is measured from the point at which a subject entered into the study to the point at which it was known to be lost to the study or the study was terminated. This assumption is potentially violated when the censoring time is arbitrarily short (Leung et al., 1997). For example, survival analysis showed that using only first-year capture histories for PIT-tagged chinook salmon passing through dams potentially underestimated survival of smolts during years when a large portion of tagged individuals overwintered above dams (Lowther and Skalski, 1997). If it can be assumed that loss to a study over time affects all individuals in approximately the same way, regardless of which group they belong to, then arbitrary censoring time should be avoided, and if groups of individuals are disproportionately lost to the study over time, then covariates may need to be considered. For example, if tags on fish that are below a minimum size limit for harvest are less likely to be noticed by anglers, then fish size may be a necessary covariate.

For this analysis, tag-recapture data from a large-scale observational field study were evaluated. The Florida Fish and Wildlife Conservation Commission (FWC) placed fishery observers on for-hire recreational vessels in the eastern Gulf of Mexico to collect vital statistics on reef fishes caught and released during recreational hook-and-line fishing. The objective of this analysis was to develop a model for gags, which were tagged prior to release, that could control for potential covariates on both the occurrence and timing of recapture events so that injuries and impairments could be related to subsequent mark-recapture rates. Because gags were tagged year-round, over multiple years, and over a large geographic area, it was necessary to control for potential covariates on recapture rates for fish tagged in different regions, years, and times of year. Fishing effort is variable among regions within the geographic area of this study. Effort in the Panhandle region is highest during the summer months due to increased tourism and a significant pulse in offshore fishing effort during the short time period when red snapper *Lutjanus campechanus* is open to recreational harvest. The Big Bend region is located within a sparsely populated area of the state, and fishing effort is comparably low there year-round. Tampa Bay is a population center, and fishing effort in the adjacent Gulf of Mexico waters is highly dispersed across a longer fishing season and among low-relief natural-bottom habitats distributed across the broad, shallow West Florida continental shelf. Fishing effort also potentially varied across time due to changes in the length of the recreational harvest season within and among years in this study. Fish that were tagged in earlier years were vulnerable to targeted fishing effort distributed across more months of the year and for more years, whereas fish tagged later in the study were subject to concentrated effort over a variable number of months each year across fewer years. Another unexpected factor that potentially influenced fishing effort during the second year of this study was the Deepwater Horizon oil spill in the Gulf of Mexico. Fishing effort following the episodic event in 2010 was potentially influenced by months-long closures to all fishing in contaminated areas and by more persistent public perceptions believed to influence tourism and seafood consumption throughout the region. It was hypothesized that the timing of recapture events for individual fish in this study was correlated with multiple extraneous factors unrelated to the initial exposure to catch-and-release. Survival analysis was used because the duration of time at large before first recapture could provide a more precise measure of recapture rate in response to covariates than a binomial (recaptured = yes or no) variable.

2. Methods

2.1. Study design

Since June 2009, fishery observers have accompanied passengers on fishing vessels in Florida that offer for-hire recreational fishing trips and target reef fishes in the eastern Gulf of Mexico. Operators of more than 160 vessels participated in the year-round study, and vessels were randomly selected each month for observer coverage from each of three regions: (A) the northwestern Panhandle, (B) nearshore areas adjacent to Tampa Bay, and (C) areas adjacent to Tampa Bay approximately 80–100 miles offshore (Fig. 1). Monthly sample quotas were assigned to two trip types in areas A and B: (1) single day charter trips and (2) single day headboat (large party boat) trips. Monthly sample quotas for a third trip type, multi-day (>24 h) headboat trips, were assigned in area C. Fishery observers boarded vessels along with paying passengers and directly observed recreational fishing during each sampled trip.

In addition to randomly sampled recreational fishing trips, charter vessels were hired as part of an ongoing study of red snapper in area A and in a fourth region commonly referred to as Florida's Big Bend (area D in Fig. 1). The purpose of the hired charter trips was to tag and release red snapper caught using recreational fishing methods. Gags caught during these trips were also tagged and released. During hired charter trips, volunteer anglers fished using recreational hook-and-line gear supplied by the vessel. Captains were asked to target red snapper but were given no instructions from scientific crew on where to fish or how to target fishing. All hired charter trips were conducted from March through May in 2010–2012.

Table 1
Description of release condition categories for gag observed during recreational hook-and-line fishing.

Condition category	Description
Good	Fish immediately submerged without the assistance of venting and did not suffer internal hook injuries or visible injury to the gills.
Fair	Fish did not immediately submerge, or submerged with the assistance of venting, and did not suffer internal hook injuries or visible injury to the gills.
Poor	Fish remained floating at the surface, suffered internal hook injuries, suffered visible injury to the gills, or any combination of the three impairments.

During each randomly sampled recreational trip or hired charter trip, one or two fishery observers monitored recreational anglers during hook-and-line fishing. Depth and latitude/longitude (degrees and minutes) were recorded at each fishing station. For each gag caught and released, observers recorded information that included (1) size (mm midline length), (2) location where the hook was embedded (lip or jaw, inside mouth, esophagus, gill, gut, eye, or external), (3) whether the fish was bleeding (indicating gill injuries), (4) the presence or absence of barotrauma symptoms (swollen bladder, everted stomach, extruded intestines, or exopthalmia), (5) whether the swim bladder was vented to reduce buoyancy from barotrauma prior to release (observers assisted with venting fish when asked to do so by the vessel mate or captain; whether the swim bladder was deflated or the everted stomach was punctured was also recorded), and (6) the observed condition of the fish at the surface following release (good = swam below surface immediately; fair = did not submerge immediately, then swam below surface; poor = floating on surface and unable to submerge; dead = unresponsive and presumed dead upon release; preyed = visually preyed upon at or near the surface).

Prior to release of live discards, each fish was marked with a Hallprint dart tag inserted in the front dorsal area and securely anchored between the first and second leading dorsal fin rays. Each dart tag had an external monofilament streamer labeled with a unique tag number, the phone number for FWC's toll-free tag-return hotline, and the word REWARD. The tagging program was widely publicized throughout the study region and a free t-shirt was offered to any angler who called in tag-return data. Participating charter and headboat vessel operators were also provided a supply of postage-paid cards that were filled out and returned to FWC when tagged fish were encountered. Information collected for each tag return included the tag number, date of recapture, fish size, and approximate location. Recaptured fish were also encountered directly by fishery observers during sampled charter trips.

2.2. Immediate mortalities and live release conditions

Immediate mortality was calculated as the percentage of all gags that were caught (and not harvested) with a release condition of either dead or preyed. This percentage included gags that were released without a tag because they were dead on retrieval (usually attacked by a predator during ascent) and gags that were tagged and were either unresponsive and presumed dead or visibly preyed upon at the surface. Tagged fish that suffered immediate mortality were not included in latent mortality calculated from tag-recapture rates.

Live gag discards from each region were assigned to one of three release condition categories described in Table 1. Logistic regression was used to compare the presence of barotrauma symptoms among gags observed in the three release condition categories. Generalized linear models and Tukey post hoc tests were used to compare mean capture depth and mean size of gags among release condition categories and regions.

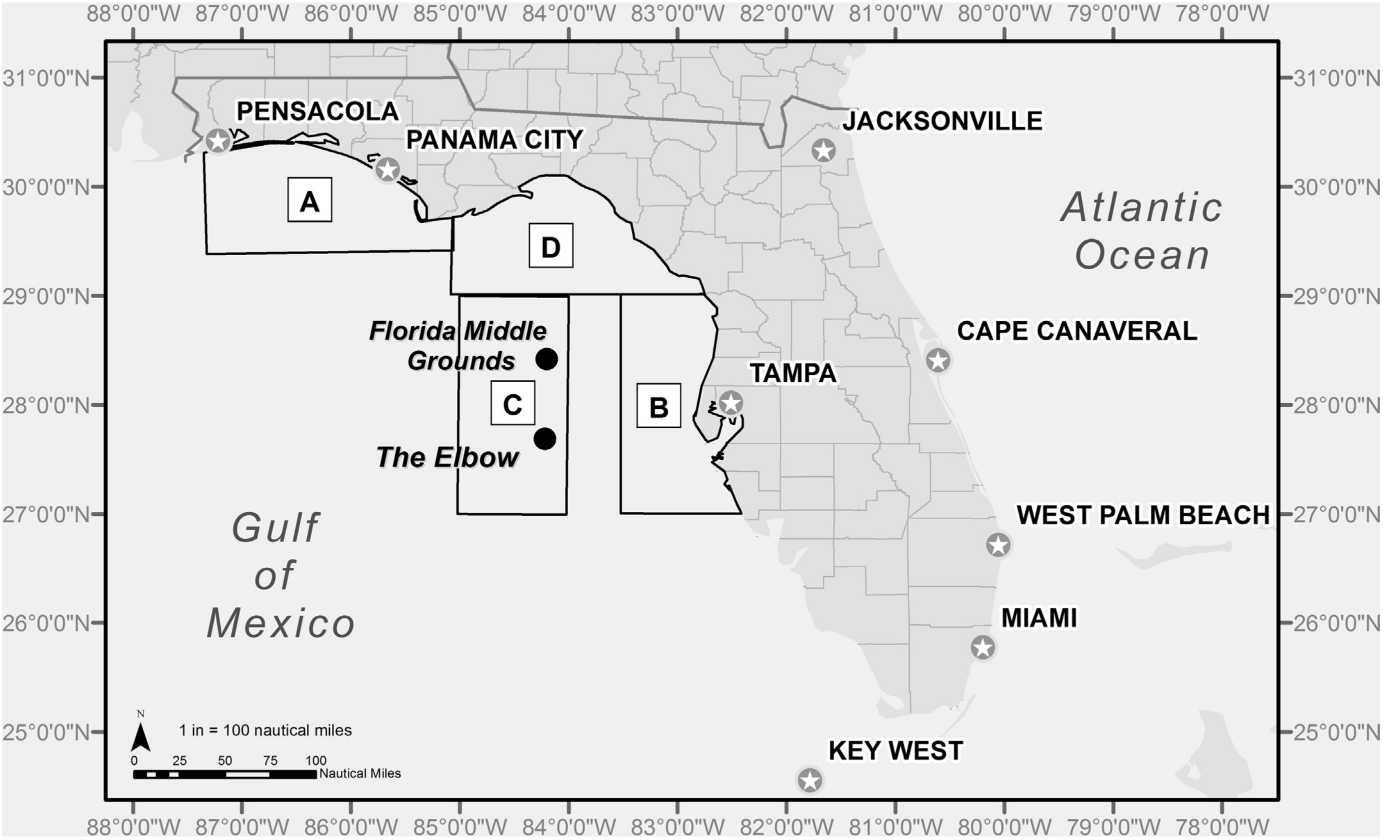

Fig. 1. Regions within the study area include the Panhandle region (A), Tampa Bay nearshore region (B), Tampa Bay offshore region (C), and Big Bend region (D).

2.3. Relative survival of live discards

The objective of this portion of the data analysis was to test hypotheses about the relative survival for fish released in different treatment groups (live release condition categories) specifically in response to catch-and-release events. To evaluate the timing and occurrence of recapture events among gags in condition categories 2 and 3 relative to condition category 1, the PHREG procedure in SAS was used to construct a proportional hazards regression model. The proportional hazards model is a form of survival analysis first described by Cox (1972). The model is used to estimate the hazard (h) for an individual (i) in a population of tagged fish to experience a reported recapture event at time t, and the time-specific recapture reporting rate is described by the hazard function:

$$h_i(\mathrm{t}) = \lim{}_{\Delta \mathrm{t}} \rightarrow 0 \frac{pr(\mathrm{t} \le \mathrm{T} < \mathrm{t} + \Delta \mathrm{t} \,\middle|\, \mathrm{T} \ge \mathrm{t})}{\Delta \mathrm{t}} \quad (2)$$

The numerator is the conditional probability that an individual tagged fish is reported as a recapture, where T is the occurrence of the event between times t and t+Δt, given the event did not already occur before time t. Dividing this probability by the width of the interval (Δt) yields the recapture reporting rate per unit of time, and taking the limit as the interval approaches zero gives an instantaneous rate. The instantaneous rate allows for variability in recapture reporting rates to be explained with a high degree of precision so that significant differences between groups of tagged fish may be detected.

When each tagged fish has a set of measurements (x1 to xk) associated with it, the hazard function is explained by the proportional hazards regression model:

$$h_i(\mathrm{t} \,|\, x_{il} \ldots x_{ik}) = h_0(\mathrm{t}) * \exp(\beta_l x_{il} + \ldots \beta_k x_{ik}) \quad (3)$$

where $h_0(t)$ is the baseline hazard function that describes the hazard for a recapture reporting event for a reference group within the population and the second term is the linear function for a set of k covariates. To demonstrate how the baseline hazard function works, consider a simple model with one variable x, where x=0 if a fish is released at the surface and re-submerges on its own and x=1 if the fish is unable to re-submerge. When x=0, equation 3 reduces to $h_0(t)$, which is the risk for individuals within the reference group to be reported as a recapture at time t. Equation 3 reduces to $h_0(t)*\exp(\beta)$ when x=1, where the second term is the proportionate increase or decrease in that risk for individuals in the impaired group. Adding other covariates to this model controls for potential confounding effects on both the reference group and the impaired group. When the instantaneous rates of $h_i(t)$ for two individuals are compared as a ratio (referred to as the hazard ratio, notated here as H), $h_0(t)$ cancels out to yield:

$$\hat{H} = \frac{\exp(\beta_1 X_{i1} + \cdots + \beta_k X_{ik})}{\exp(\beta_1 X_{j1} + \cdots + \beta_k X_{jk})} \quad (4)$$

and the two rates vary proportionally with respect to each other over time (Allison, 2010). Thus, the hazard ratio for two treatment groups is an instantaneous rate that is interpreted much like the rate ratio described in Eq. (1), with the added feature of controlling for covariates on not just the occurrence of recapture events, but also on the more precise measure of the timing of recapture events within and among treatment groups. The confidence interval for the hazard ratio point estimate is calculated as:

$$\mathrm{CI} = \hat{H} \times \exp(\pm Z_{1-\alpha/2} \times \mathrm{s.e.}\hat{H}) \quad (5)$$

The response variable used for this analysis was the number of days a fish was at large before it was either reported as a recapture (coded as 1) or censored (coded as 0). Timing of each recapture event was defined as the number of days from the time that a fish was tagged and released until its first reported recapture. Once a fish was reported as recaptured the first time, survival was confirmed and observation times for subsequent recapture events were not included in the analysis. Fish that were not reported as recaptured were treated as censored observations, and time in the study was defined as the number of days from when individual fish were tagged until December 31, 2012. The treatment to be tested was release condition category, which was included as an independent class variable in the proportional hazards model. Control variables that were also tested for entry into the model included class variables for region, time of year (month), and year that fish were initially tagged and released; continuous variables for capture depth (meters) and size at original capture (mm midline length); and possible interaction terms. Proportionality is an important assumption of the proportional hazards model, and the form of the underlying hazard function was expected to vary across years of entry into the study due to variable fishing effort and species targeting in response to increased harvest restrictions, among other potential factors previously discussed. Annual differences in tag-recapture rates were not of direct interest for this analysis, and to adjust for this confounding effect the proportional hazards model was stratified using the STRATA statement in the PHREG procedure. This procedure constructs separate partial likelihood functions for each stratum (fish tagged in the same year), which are multiplied so that single parameter estimates for β_1 to β_k that maximize the function can be selected (Allison, 2010). Akaike's information criterion (AIC) values based on partial likelihood of the second term in Eq. (3) reported in SAS output were used along with the forward selection procedure to select among potential covariates for the timing of recapture events.

A key assumption for this application of the proportional hazards model, as well as the relative survival model applied by Hueter et al. (2006), is that the probability of encountering a tagged fish that survived catch-and-release is not influenced by the treatment group that the fish belongs to. It is possible that fish in different treatment groups were more or less likely to be recaptured during an initial recovery period immediately following catch-and-release due to differential behavior responses. However, over the range of observation times for which individual fish in each treatment group remained in this study until they were either recaptured or censored (as much as 3.5 years), it was assumed that the effect of short-term differences in catchability among treatment groups was negligible. Other assumptions by Hueter et al. (2006) that also apply to this model are that natural mortality and artifacts of tagging (tag shedding, tag fouling, non-reporting, etc.) affect all fish in the same way, regardless of their condition upon release. Two other assumptions specifically related to staggered entry times and censoring times for individuals in this study are (1) that captured fish were encountered randomly in the fishery, and the probability that an individual did not recover from the catch-and-release event was not influenced by time of entry into the study; and (2) that for an individual censored at the end of the study after *t* days at large, the probability of being reported as a recapture was the same as for all other individuals released in the same treatment group.

2.4. Overall discard mortality estimation

The objective of this portion of the analysis was to estimate overall discard mortality for gags in all condition categories caught and released from various depths in the recreational hook-and-line fishery. To estimate depth-dependent discard mortality, the number of observed gags released in good (N_1), fair (N_2) and poor (N_3) condition categories at each 10-m depth interval (where d = 1–10 m, 11–20 m, etc.) was first multiplied by the proportion of gags in each condition category estimated to survive. Discard mortality at each depth interval (M_d) was expressed as a percentage using the following equation:

$$\hat{M}_d = \left[1 - \frac{(N_1 \times S_1) + (N_2 \times \hat{H}_2) + (N_3 \times \hat{H}_3)}{N_1 + N_2 + N_3}\right] \times 100 \quad (6)$$

where S_1 is absolute survival following catch-and-release for gags released in good condition (which is not truly known), and $\hat{H}_2$ and $\hat{H}_3$ are estimated survival proportions for gags released in fair and poor condition (respectively), relative to gags released in good condition, as derived from the proportional hazards model.

Ideally, absolute survival for gags in condition category 1 (S_1) should be measured; however, because all fish had to be captured in order to be tagged and released, there was no true control to reference this treatment group to. Because the majority of fish released in good condition were caught from shallow depths, where barotrauma should be minimal, and because individuals with hook injuries, visible gill injuries, potential internal injuries related to venting, or swimming impairments at the surface were excluded from this treatment group, it is reasonable to assume that discard mortality in this treatment was low. Discard mortality was also not expected to be greater than overall values reported from shallow depths in other studies, which included fish in more severely impaired conditions than the reference group in this study. A literature review produced during the data workshop for SEDAR (Southeast Data Assessment and Review) number 33 in support of the 2013 Gulf of Mexico gag stock assessment (under way) reported low overall discard mortality estimates in nearshore fisheries, including one unpublished study for gags caught with hook-and-line gear (mean depth 5.7 m, 7.2% discard mortality) and several published studies for other fisheries that operate near shore (10 studies for 6 species, range 2.13–14.4% discard mortality; SEDAR, 2013). Therefore, mortality of gags released in good condition without the need for venting and with no visible injuries or impairments is expected to be less than 15%. For this analysis, overall depth-dependent discard mortality was calculated separately under three assumptions for S_1: (1) that 100% of gags in good condition survive catch-and-release ($S_1 = 1.000$); (2) that as few as 85% of gags in good condition survive ($S_1 = 0.850$); and (3) that a median of 92.5% survive ($S_1 = 0.925$). For the median assumption, uncertainty around overall discard mortality estimates for each depth interval was calculated by substituting S_1 in Eq. (6) with lower and upper assumed values of 0.85 and 1.0, and substituting $\hat{H}_2$ and $\hat{H}_3$ in Eq. (6) with lower and upper 95% confidence limit values (calculated from Eq. (5).

3. Results

3.1. Immediate mortalities and live release conditions

Only 11 gags that were not retained by anglers suffered immediate mortality, which was a small percentage (<1.0%) of the total discards observed. Of the 3954 live gag discards observed, the majority (77.8%) were released in good condition (condition category 1), and this was largely driven by the abundance of gags encountered during trips in the Tampa Bay nearshore region (Table 2). While fewer gags were observed in the Panhandle and Tampa Bay offshore regions, less than half were in good condition, compared to more than 90% in the relatively shallow Tampa Bay nearshore region (Table 2). Similarly, in the shallow Big Bend region, 92% of gags observed were in good condition. Gag discards from the Tampa Bay nearshore region were significantly smaller, and gag discards in the Panhandle and Tampa Bay offshore regions were captured in significantly deeper depths (29.76 and 41.10 m respectively) compared to other regions and were also significantly different from each other ($\alpha = 0.05$, Table 2). More than half of gag

Table 2
Characteristics of observed gag discards tagged and released by region. Mean ± SD notated with different lowercase letters represent significant differences ($p < 0.05$) from GLM and Tukey post hoc tests.

	(A) Panhandle	(B) Tampa Bay nearshore	(C) Tampa Bay offshore	(D) Big Bend
Numbers of fish tagged:				
Condition 1 (%)	294 (43.43)	2435 (94.02)	180 (33.96)	146 (93.00)
Condition 2 (%)	355 (52.44)	83 (3.20)	287 (54.15)	3 (1.91)
Condition 3 (%)	28 (4.14)	72 (2.78)	63 (11.89)	8 (5.10)
Numbers of fish recaptured:				
Condition 1 (% tagged)	46 (15.65)	217 (8.91)	19 (10.56)	10 (6.85)
Condition 2 (% tagged)	42 (11.83)	4 (4.82)	26 (9.06)	0
Condition 3 (% tagged)	4 (14.29)	3 (4.17)	3 (4.76)	0
Mean length (mm midline)	522.65 ± 117.14 (a)	462.77 ± 87.49 (b)	584.98 ± 105.20 (c)	532.24 ± 82.99 (a)
Mean capture depth (m)	29.76 ± 7.44 (a)	18.18 ± 7.45 (b)	41.10 ± 10.97 (c)	20.60 ± 3.44 (b)
Number of trips:				
Single-day charter	99	127	–	–
Directed red snapper charter	72	–	–	7
Single-day headboat	47	129	–	–
Multi-day headboat	–	–	37	–

Table 3
Odds ratios (95% CI) from logistic regressions of release condition category on the presence of barotrauma symptoms. Confidence intervals that overlap 1.00 indicate that the odds were not significantly increased or decreased among condition categories.

	Swollen bladder	Everted stomach	Extruded intestines	Exopthalmia
Condition 2 vs. 1	29.30 (15.11, 56.81)	3.81 (3.21, 4.53)	3.73 (2.34, 5.97)	6.00 (3.24, 11.11)
Condition 3 vs. 1	2.35 (1.51, 3.65)	2.98 (2.18, 4.08)	0.89 (0.21, 3.70)	6.10 (2.39, 15.57)
Condition 2 vs. 3	12.47 (5.68, 27.38)	1.28 (0.91, 1.80)	4.21 (1.00, 17.74)	0.98 (0.40, 2.45)

discards in the two regions with deeper depths were vented before release (53% in the Panhandle and 61% in Tampa Bay offshore), which is in contrast to the two shallower regions, where more than 90% of fish were released in good condition without the need for venting (Fig. 2). The greatest percentage (11.98%) of gags released in poor condition (condition category 3) was also in the Tampa Bay offshore region (compared to <5.5% for other regions). The total number of gags observed in the Big Bend was small because fewer trips were conducted there, and very small numbers of fish were released in fair or poor condition (Table 2).

Overall, across all regions, gags released in good condition were significantly smaller and were caught from significantly shallower depths than those released in fair condition (Fig. 3). Gags released in fair and poor condition also have significantly greater odds of exhibiting symptoms of barotrauma compared with those released in good condition (Table 3). A majority of gags in all release-condition categories exhibited a swollen bladder (range = 71.9% to 98.7%), which indicates at least mild barotrauma (Fig. 4); however, those in fair and poor conditions were significantly more likely to exhibit this symptom (Table 3). The presence of an everted stomach was less prevalent (Fig. 4), and gags released in fair or poor condition were 3.81 and 2.98 times more likely, respectively, to exhibit this symptom than those

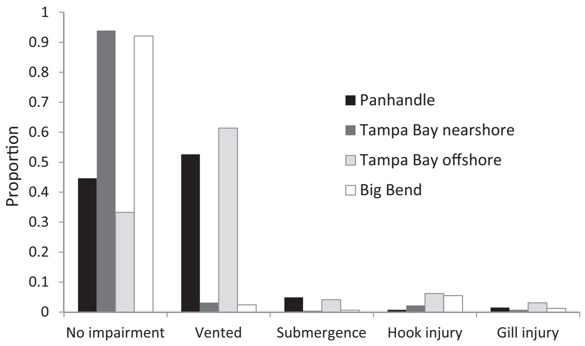

Fig. 2. Proportion of gag discards by region that exhibited no impairment or that exhibited one or more impairments at the time of release (individuals with more than one impairment symptom are included in multiple categories). No impairment means fish submerged immediately upon release without assistance from venting and did not suffer hook or gill injuries. Venting refers to deflation of the swim bladder or puncture of the stomach before a fish was released. Submergence means a fish did not submerge immediately or floated when released. Hook injury means hooks were embedded in the esophagus, gut, gill, or through the eye. Gill injury means the fish was visibly bleeding from the gills.

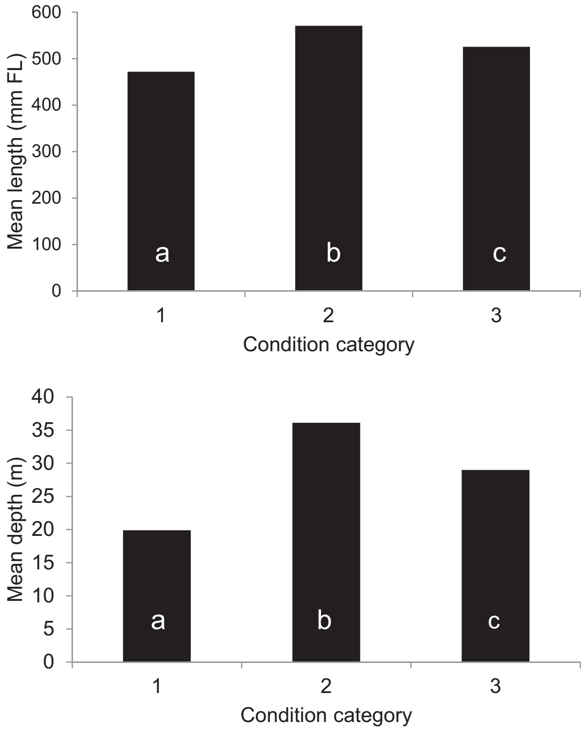

Fig. 3. Mean length of gag discards (top) and mean depth of capture for gag discards by release condition category (Table 1). Different lowercase letters represent significant differences ($p < 0.05$) from GLM and Tukey post hoc tests.

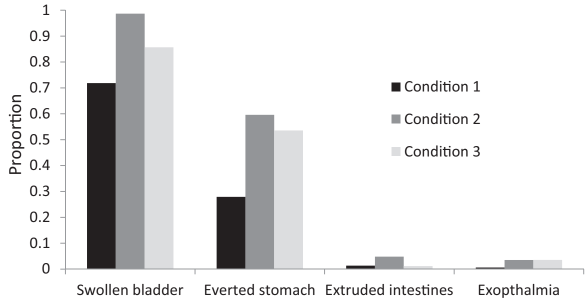

Fig. 4. Proportion of gags observed with visible barotrauma by release condition category. The odds for observing each symptom among fish in each condition category are summarized in Table 3.

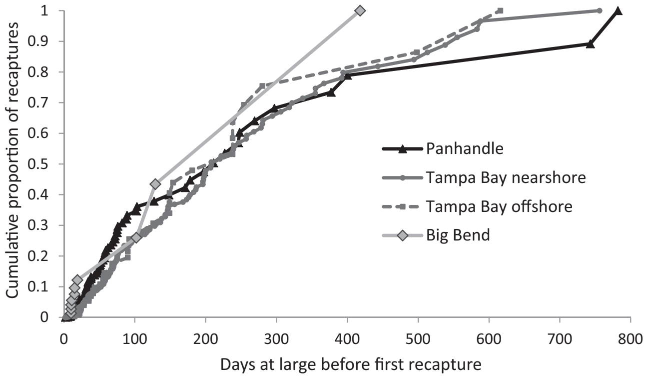

Fig. 5. Days at large before first recapture expressed as the cumulative proportion of total at-large times for all recaptured fish, by region. The median time at large before first recapture was 34 days in the Panhandle region, 55 days in the Tampa Bay nearshore region, 68 days in the Tampa Bay offshore region, and 15 days in the Big Bend region. Sample sizes for recaptured fish in each region are provided in Table 2; note the low sample size for the Big Bend region ($n = 10$).

released in good condition (Table 3). Symptoms of more severe barotrauma, including extruded intestines and exopthalmia, were rare (<5.0%) for gags observed in all release conditions (Fig. 4). When severe symptoms were present, fish were more likely to be in fair or poor condition (Table 3).

3.2. Reported tag recaptures

A total of 374 gags were reported to be recaptured, for an overall tag-return percentage of 9.46%. The tag-return percentage varied regionally, with the greatest percentage in the Panhandle region (Table 2). The region in which fish were tagged was highly correlated with time at large before the first reported recapture ($p < 0.0001$), and recaptured fish were at large for a minimum of 2 days and a maximum of 782 days before the first reported recapture (Fig. 5). Recaptured fish were at large for longer periods in the Tampa Bay nearshore and offshore regions (medians of 55 days and 68 days, respectively) compared to the Panhandle region (median = 34 days), and fish in the Big Bend region were at large for the shortest period (median = 15 days). In every region, the largest tag return percentage was from gags released in good condition (Table 2). Due to the small number of gags tagged in the Big Bend region, particularly in fair and poor condition categories, only 10 recaptures were reported, and none were from fish released in fair or poor condition; therefore, this region was excluded from the analysis for relative survival among treatment groups.

Table 4
Summary of the proportional-hazard model forward selection of independent variables on the number of days gag were at large before they were either reported as recaptured or censored at the end of the study without having been recaptured. The model was stratified by year of entry (Fig. 1). Variables tested that were not included during the forward-selection procedure were depth of capture, two-way interactions between depth with length and month, and a three-way interaction between month × region × length.

Effect entered	df	χ^2	p	AIC after inclusion
Region	2	20.995	<0.0001	4784.190
Month	11	20.895	0.035	4784.483
Length	1	4.098	0.043	4782.397
Length × month	11	24.301	0.012	4780.189
Condition category	2	7.896	0.019	4775.841

Table 5
Estimated hazard ratios ($\hat{H}$) and 95% CIs (in parentheses) for gags in Tampa Bay nearshore (TBn), Tampa Bay offshore (TBo) and Panhandle (PH) regions, after controlling for the effect of covariates on reported recapture rates (Table4 Hazard ratios are significant when the 95% CI does not overlap 1.0.

Region	$\hat{H}$	s.e.	χ^2	p
TBn vs. PH	0.574 (0.420, 0.784)	0.1589	12.221	0.001
TBo vs. PH	0.569 (0.381, 0.849)	0.2040	7.651	0.006
TBn vs. TBo	1.009 (0.689, 1.478)	0.1948	0.002	0.963

Table 6
Estimated hazard ratios ($\hat{H}$) and 95% CIs (in parentheses) for gags in condition categories 2 and 3 versus a reference group, after controlling for the effect of covariates on reported recapture rates (Table4).

Condition category	$\hat{H}$	s.e.	χ^2	p
2 vs. 1	0.664 (0.469, 0.940)	0.1772	5.324	0.021
3 vs. 1	0.506 (0.262, 0.978)	0.3365	4.105	0.043
2 vs. 3	1.314 (0.667, 2.588)	0.3460	0.6221	0.430

3.3. Relative survival of live discards

The proportional hazards model was stratified by year, and potential control variables entered into the model were region, capture depth, fish size at time of original capture, and associated interaction terms. Significant covariates selected during the forward selection procedure are summarized in Table 4 and include region, month in which fish were tagged and entered into the study, fish length at the time they entered the study, and an interaction term between month and fish length. When referenced against the Panhandle region, the hazard for recapture was significantly reduced for gags tagged and released in other regions ($\chi^2 = 20.995$ and $p < 0.0001$), which confirmed the necessity to control for variable tag-recapture rates among regions. Gags were only 57.4% as likely to be recaptured when tagged in the Tampa Bay nearshore region and 56.9% as likely when tagged in the Tampa Bay offshore

Table 7
Number of gags observed in condition categories 1, 2 and 3 (N_1–N_3) by depth interval, and estimated overall discard mortality ($\hat{M}_d$) expressed as percentage under varying assumptions of survival for gags in condition category 1 (S_1). Uncertainty around point estimates for $\hat{M}_d$ when S_1 equals the median value 0.925 is provided in parentheses and was calculated by substituting lower and upper 95% confidence limits for $\hat{H}_2$ and $\hat{H}_3$ from Table 6 and lower and upper assumed values of 0.850 and 1.000 for S_1 into Eq. (6). See also Fig. 6.

Depth (m)	N_1	N_2	N_3	Percentage discard mortality ($\hat{M}_d$)		
				$S_1 = 1.000$	$S_1 = 0.925$	$S_1 = 0.850$
1–10	216	1	6	1.48	8.74 (0.09, 16.75)	16.01
11–20	1687	17	50	1.73	8.95 (0.12, 17.05)	16.16
21–30	850	226	49	8.90	14.57 (1.30, 25.21)	20.23
31–40	231	308	31	20.84	23.88 (3.36, 38.79)	26.92
41–50	44	111	29	28.06	29.85 (3.97, 47.25)	31.64
51–60	27	46	5	22.98	25.58 (3.68, 41.24)	28.17
61–70	0	12	0	33.60	33.60 (6.00, 53.10)	33.60
>70	0	7	1	35.58	35.58 (5.53, 55.69)	35.58

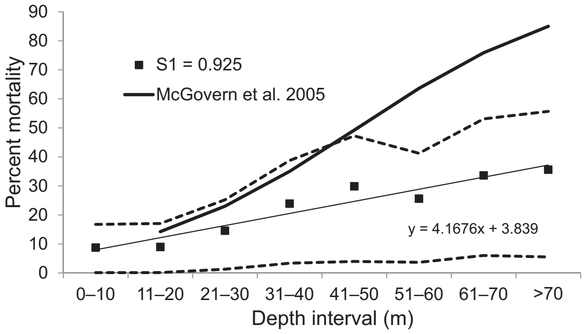

Fig. 6. Overall estimated percentage mortality for gags observed, by 10-meter depth interval. Point estimates (squares) assume 92.5% survival of gags released in condition category 1 ($S_1 = 0.925$), and the linear relationship (light line) between point estimates and the median for each depth interval is significant ($p < 0.001$, $R^2 = 0.917$). Uncertainty around point estimates is shown by the dashed lines (see Table 7 for values). A low number of sampled trips took place in depths >60 m, and gags captured in depths >70 m are combined into a plus group (see Table 7 for sample sizes). Percentage mortalities from McGovern et al., 2005 (dark line) are plotted for comparison.

region (Table 5). Depth of original capture and interactions between depth and other covariates were not significant. The release condition category was significant ($\chi^2 = 7.896$ and $p = 0.0193$) and, after covariates were controlled for, the hazard (or probability) for recapture was significantly reduced for fish in condition categories 2 and 3 when referenced against fish in good condition, category 1 (Table 6). Fish in condition category 2 were only 66.4% as likely to be recaptured as fish in condition category 1. Fish in poor condition, category 3, were only 50.6% as likely to be recaptured as fish released in good condition. There was no significant difference in relative survival between fish in condition categories 2 and 3 (Table 6).

3.4. Overall discard mortality estimates

Discard mortality over all gags observed within the recreational hook-and-line fishery was calculated at 10-m depth intervals (Table 7). For the median survival value, at which 92.5% of gags observed in good condition are assumed to survive catch-and-release ($S_1 = 0.925$), the overall discard mortality percentage for gags was estimated to be less than 15.0% (range of uncertainty, 0.1–25.2%) in shallow depths to 30 m. There was a significant positive linear increase in discard mortality point estimates with depth ($p < 0.001$, $R^2 = 0.917$). Discard mortality estimates gradually increased from 23.9% (3.4–38.8%) at depths between 31 and 40 m to 35.6% (5.6–55.7%) at depths greater than 70 m (Fig. 6).

4. Conclusions and discussion

The results of this analysis provide some important conclusions that are informative regarding the survival of gag discards in the recreational hook-and-line fishery. Perhaps most important, in the region where the majority of gags were encountered, gags were captured in relatively shallow depths and released in good condition, meaning they did not require venting in order to immediately submerge and they did not sustain internal injuries from embedded hooks or visible injury to the gills during handling. Immediate mortality was low (<1%) and was similar to another published study that reported predation mortality of 1.3% observed for hooked fish released at the surface (Overton et al., 2008). However, in regions where fishing took place in significantly deeper depths, gags were released in poorer condition and relative survival was significantly reduced for fish released in fair or poor condition compared to those released in good condition. A large percentage of fish in the fair condition category were vented prior to release; however, the result that these fish suffered greater mortality compared to unvented fish in good condition should not be interpreted as a negative effect from venting. The act of venting does require additional handling time and introduces the possibility of internal injury resulting from improper venting techniques. However, fish in fair condition were significantly larger and were caught from significantly deeper depths than fish that did not require venting to re-submerge, and it is possible that additional stress unrelated to the act of venting itself contributed to their reduced survival. It is also possible that vented fish would have suffered greater mortality if they had not been vented and thus unable to re-submerge.

This was an observational study that measured true conditions experienced by fish captured and released in an actual fishery. By collecting data on a variety of impairments and condition factors in the field, fish in the best condition could be distinguished, which allowed for meaningful comparisons with fish released in poorer condition. Given the highly variable conditions of capture, handling and release that fish are potentially exposed to in recreational fisheries, the detection of significant differences in relative survival between release condition categories is an unequivocal result. The utility of the proportional hazards model to effectively control for variable fishing effort across regions and across years is also demonstrated. However, confidence intervals around hazard ratios for gags in fair and poor condition were wide, and this analysis could not compare fish released in good condition to a true control, because they had to be captured and handled in order to be tagged. A potential source of mortality that was not measured in this study is predation of fish released in good condition as they swim through the water column and return to bottom habitats. To account for the unknown sources of mortality for the control group, an acceptable range of survival percentages was selected and incorporated into uncertainty around estimates of overall discard mortality. Overall estimated discard mortality in shallow water, where nearly 80% of fish in the control group were observed, was approximately 9% (range of uncertainty 0.09– 17.05%) at depths up to 20 m and approximately 15% (1.30–25.21%) between 21 and 30 m. This range is comparable to the two other studies for gag. One published tag-recapture study estimated overall mortality to be 14.3% and 23% for gags released in depth intervals of 11–20 m and 21–30 m, respectively (McGovern et al., 2005; Fig. 6). At shallower depths (mean 5.7 m), another unpublished study reported 7.2% of gags ($n = 111$) caught with hook-and-line gear suffered mortality when held in cages for 48 h (Flaherty et al., 2011). Both estimates included mortalities from hooking injuries, gill injuries and barotrauma (to the extent that it was present in shallow depths). The cage study excluded potential mortality from predation during release, whereas the tagging study included any mortality (including that unrelated to catch-and-release).

Two published mark-recapture studies for gag and other grouper species cite diminished tag returns as evidence of greater mortality with increased depth. Wilson and Burns (1996) reported reduced recapture percentages with depth for gag, scamp (*Mycteroperca phenax*) and red grouper (*Epinephelus morio*) tagged in the Gulf of Mexico (between 26 and 30 degrees latitude adjacent to the west coast of Florida) during 1990–1994. Likewise, McGovern et al. (2005) reported reduced percentages of recaptures and greater estimated mortality with increased depth for gags tagged in the Atlantic Ocean between North Carolina and the Florida Keys during 1995–1998. While there were few changes in fishing regulations during the 1990s that would have affected fishing pressure across years, neither of these studies controlled for the potential effect of variable fishing effort among regions in the respective geographic areas. In the McGovern et al. (2005) study, 81% of gag were tagged in South Carolina; however, the authors noted that recapture percentages were greater off Florida and attributed this observation to the fact that gag spawning aggregations at depths of 49–91 m along the narrow continental shelf are more accessible to fishermen in that area. This then raises the question of whether reduced recapture rates in greater depths may be explained, at least in part, by comparatively less fishing effort offshore in the region where the majority of fish were tagged.

Unlike the two other mark-recapture studies for gag, reported recapture percentages in this study did not decline with increased depth. Overall recapture percentages for gags tagged in the two regions adjacent to Tampa Bay were similar in the offshore and nearshore areas (9.06% and 8.65%, respectively), even though fishing effort offshore is low due to inaccessibility, takes place at much greater depths (mean = 41.1 m offshore versus 18.2 m nearshore), and only 33% of gags were released in good condition (compared with 94% nearshore). This may be attributed to exceptional cooperation by the small number of headboat operators who exclusively offer multiday fishing trips in this region and that also allowed fishery observers from FWC to tag and release fish during their trips. In the Panhandle region, fewer than half (45%) of gags observed were released in the best condition, and fishing also took place in relatively greater depths (mean = 29.8 m) than in the Tampa Bay nearshore region, yet the highest overall tag-recapture percentage (13.6%) was from this region. Once the effect of regional fishing effort was controlled for, the proportion of gags that were released in fair and poor condition at greater depths in this study translated into a significant increase in overall estimates of discard mortality with increased depth. However, the band of uncertainty for estimates in this study was wide at depths >30 m due to higher proportions of gags in fair or poor condition and the large confidence intervals around estimates of S_2 and S_3. Even given the wide band of uncertainty around estimates in this study, the increase in mortality with depth was much more gradual compared to estimates from the previous study in the Atlantic, where variable recapture and reporting rates were not controlled for (Fig. 6).

The greatest concentration of recreational fishing effort in the Gulf of Mexico is off the west coast of Florida (Hanson and Sauls, 2011), and interpreting low recapture percentages in the Tampa Bay nearshore region as evidence that gags suffered greater discard mortality in shallow depths would have profound implications for fisheries management and stock assessments. The shallow west Florida continental shelf is an important staging area for sub-adult gags before migrating offshore (Koenig and Coleman, 1998; Switzer et al., 2012), and sub-adult gags are highly abundant and vulnerable to the nearshore recreational fishery (as evidenced by this study). For investigators interested in comparing the relative recapture rates of released fish in other large-scale tag-recapture studies, this analysis demonstrates the importance of understanding and accounting for covariates on tag-recapture rates before interpreting results. It was expected during the design of this study that variable fishing pressures among regions would influence encounter rates for tagged fish. Changes in fishing regulations over the course of this study, however, were not anticipated. Prior to 2011, recreational harvest was open during most months of the year, whereas recreational harvest of legal-size gag from federal waters was restricted to September 16–November 15 in 2011 and July 1–October 31 in 2012. Fish tagged and released just prior to the opening of a recreational season may be encountered after a shorter time at large, compared with fish tagged at other times of the year, simply due to increases in targeted fishing effort during the season. Therefore, it was important to control for the month and year in which fish were tagged and released. Examining interactions of covariates also helped interpret the combined effects of variable closed seasons with a minimum size limit (559 mm), which remained unchanged during this study. The hazard ratio for length in this model was 1.148, which means that for each 100 mm increase in the size of fish at the time they were tagged, the hazard of recapture increased 14.8%. This result was counterintuitive, given that fish in good condition were significantly smaller than those in fair or poor condition. When the interaction between fish size and month was revealed, it was clear that something other than release condition alone was influencing reporting rates for larger fish. This interaction may be explained by increased targeting of legal-size fish during months when recreational harvest is permitted. Also, if anglers are less likely to notice tags on fish that must be released, then tags on legal-size gags may be noticed less often during months when harvest is closed. Since sublegal-size gags must be released year-round, tags may not be noticed or may be reported even less often. By including length and the interaction between length and month as covariates, the potential effects of the minimum size limit and the harvest season on the timing of first reported recapture were controlled for in this analysis. In conclusion, it is important that researchers be aware of potential confounding effects when designing and interpreting results for tag-recapture studies, particularly those that depend on commercial and recreational fishers for tag-return observations, and that they can adequately account for those effects in tag-recapture models.

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