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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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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

by

Beverly J. Sauls

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
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DEDICATION

To my parents, who taught me to never give up,

and my friends who kept me going.

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ABSTRACT

The objectives of this study were to measure injuries and impairments directly observed from gags *Mycteroperca microlepis* caught and released within a large-scale recreational fishery, develop methods that may be used to rapidly assess the condition of reef fish discards, and estimate the total portion of discards in the fishery that suffer latent mortality. Fishery observers were placed on for-hire charter and headboat vessels operating in the Gulf of Mexico from June 2009 through December 2012 to directly observe reef fishes as they were caught by recreational anglers fishing with hook-and-line gear. Fish that were not retained by anglers were inspected and marked with conventional tags prior to release. Fish were released in multiple regions over a large geographic area throughout the year and over multiple years. The majority of recaptured fish were reported by recreational and commercial fishers, and because fishing effort fluctuated both spatially and temporally over the course of this study in response to changes in recreational harvest restrictions and the Deepwater Horizon oil spill, it could not be assumed that encounter probabilities were equal for all individual tagged fish in the population. Fish size and capture depth when fish were initially caught-and-released also varied among individuals in the study and potentially influenced recapture reporting probabilities. Therefore, it was necessary to control for potential covariates on encounter and reporting rates for individual tagged fish, and the Cox proportional hazards regression model was used to control for potential covariates on both the occurrence and timing of recapture reporting events so that relative survival among fish released in various conditions could be compared. A total of 3,954 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 meters 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 reporting rates for different sized discards among regions and across months and years when individual fish were initially captured, tagged and released. Gags released within the recreational fishery in fair and poor condition were 66.4% (95% C.I. 46.9 to 94.0%) and 50.6% (26.2 to 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 ten meter 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 up to 30 meters, to 35.6% (5.6–55.7%) at depths greater than 70 meters ($p < 0.001$, $R^2 = 0.917$). This analysis demonstrated the utility of the proportional hazards regression model for controlling for potential covariates on both the occurrence and timing of recapture events in a large-scale mark-recapture study and for detecting significant differences in the relative survival of fish released in various conditions measured under highly variable conditions within a large-scale fishery.

CHAPTER 1: INTRODUCTION

Note to Reader

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Life History

Gag *Mycteroperca microlepis* is one of multiple species in the U.S. portion of the Gulf of Mexico that is managed in the reef fish complex by the Gulf of Mexico Fisheries Management Council. The species is managed as a single stock throughout the region and is most abundant in the eastern Gulf, particularly along the continental shelf adjacent to the west coast of Florida. The West Florida Shelf is characterized by a broad, shallow, gently sloping carbonate platform (Hine, 2013). Important structural habitats for sub-adult and adult gags include patchy, low-relief natural reefs and rocky ledges associated with ridges that run parallel to the Florida peninsula, which are a geologic feature of the region. Current understanding of spawning in the northern Gulf of Mexico is limited to known aggregation sites offshore in the eastern region, often associated with relic reef structures, including Madison Swanson and Steamboat Lumps that were established as marine protected areas specifically to protect gag (Coleman et al., 2000). Reproductive connectivity with the Campeche Bank in Mexico was also hypothesized by Switzer et al. (2012), but is unconfirmed. Larvae settle in high salinity seagrass beds in open bays, such as Apalachicola Bay and around Cedar Key, Florida, and lower reaches of estuaries, including Charlotte Harbor, Sarasota Bay and Tampa Bay (Switzer et al., 2012; Koenig and Coleman, 1998). These habitats also serve as important nursery areas, and as juveniles increase in size they leave the protection of seagrass beds and move into hard bottom habitats nearshore in the Gulf of Mexico (Stallings et al., 2010). Due to their life history and the high concentration of recreational fisheries in lower estuaries and nearshore, gags are vulnerable to fishing pressure at a young age.

Recreational Fisheries and Management History

Gags are highly sought by recreational anglers in the Gulf of Mexico, and more than 90% of total recreational catch for the species comes from the eastern Gulf (SEDAR, 2013). The Gulf region supports some of the largest recreational fisheries in the United States, and the greatest concentration of effort is along the west coast of Florida (Hanson and Sauls, 2011). Between the 1980's and the 2000's, there was a sustained increase in the numbers of recreational fishing licenses, recreational for-hire vessel licenses, and recreational vessel registrations issued in Florida, which was also reflected in survey estimates for numbers of participants and saltwater angler trips from the west coast of Florida (Hanson and Sauls, 2011). Total recreational catch of gag in the Gulf of Mexico increased over this same time period, in spite of a series of increasingly restrictive harvest control measures that were intended to reduce recreational fishing pressure (Figure 1).

Recreational fisheries in the Gulf are currently managed with an allocation of 61% of the total allowed catch for gag, which includes estimated removals attributed to mortality of discarded fish (GMFMC, 2008). Before harvest restrictions were implemented in the 1990's, only a small portion of the total annual recreational catch for gag was discarded (29.4% on average); however, as harvest controls became more restrictive over time, the discarded portion increased (Figure 1). The gag stock in the Gulf of Mexico was classified as overfished and undergoing overfishing in 2009 (SEDAR, 2009), and recreational harvest has been closed for a majority of months since 2011 to allow the stock to recover. In 2011–2012, recreational anglers fishing from the west coast of Florida caught an estimated 1 million gags annually (including harvested and released fish), down from 2.2 to 4.5 million gags during the last decade (Figure 1), and in recent years, discards have accounted for an average of 90.4% of the total annual recreational catch (Figure 1). Therefore, even when a small percent are estimated to suffer mortality, a significant portion of total fishing mortality may be attributed to discards. Stock assessments for gag in the Gulf of Mexico have applied mortality percentages to discards that range as low as 0% in shallow depths to greater than 80% in capture depths exceeding 70 meters (reviewed in SEDAR, 2013).

In the face of increasing effort and an increasing magnitude of discards, a new management approach was adopted in 2008 with the goal of minimizing mortality of reef fishes released in recreational fisheries. The Gulf of Mexico Fishery Management Council and the State of Florida implemented a suite of measures that required the use of non-stainless steel circle hooks, possession and use of a hollow venting tool, and possession of a de-hooking tool when fishing for species managed in the reef fish complex, including gag. The hook requirement was supported by a review of 43 studies for 25 species which found that circle hooks had a greater tendency to set in the lip or jaw and reduced mortality rates attributed to hook injuries by approximately 50% overall when compared with J hooks (Cooke and Suski 2004). However, studies to evaluate the potential benefits of circle hook use and venting specifically for reef fishes were limited at the time regulations were implemented. Since 2008, data collected from discards observed in the recreational fishery indicate that circle hooks may benefit multiple species in the reef fish complex, but the prevalence of potentially lethal hooking injuries in gag is low for both circle hooks and other hook-types (Figure 2; Sauls and Ayala, 2012). Studies on the benefits of venting for reef fishes, on the other hand, have produced conflicting results (Wilde, 2009) and further research is needed to quantify potential reductions in discard mortality from this practice. The venting rule was rescinded this year (2013) to allow alternative methods, such as rapid descent to quickly recompress fish, or best practice methods that include releasing fish at the surface without venting when barotrauma is not a concern (GMFMC, 2013).

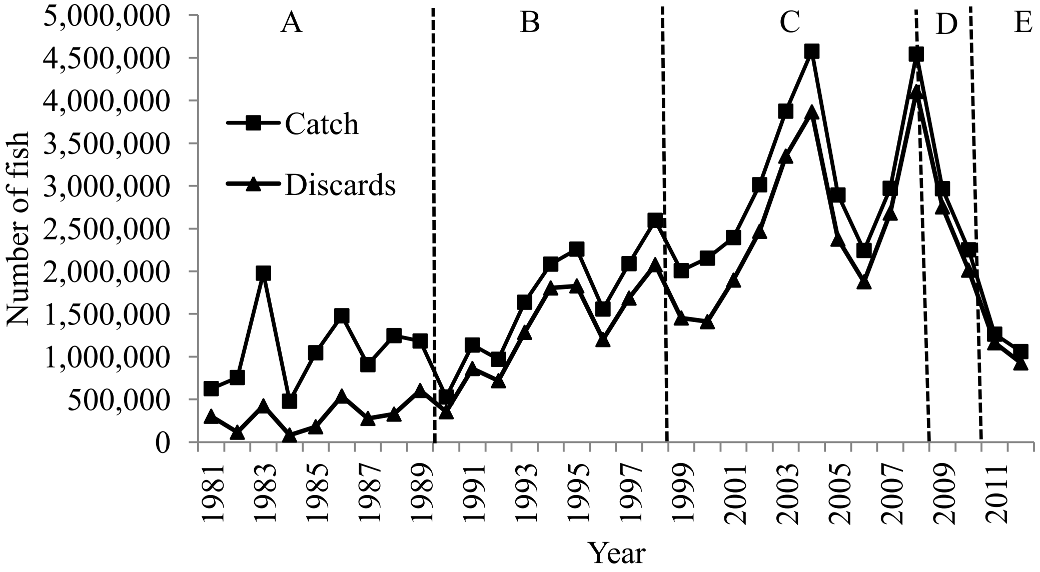

Figure 1. Estimated numbers of gags caught (harvest and discards combined) and discarded by anglers on private recreational boats and charter boats in the U.S. Gulf of Mexico. During the time interval indicated by the letter A, no recreational harvest limits were in place. In interval B, a 20” size limit and an aggregate bag limit of five shallow water grouper (including gag) per person were in place. The minimum size limit was increased to 22” at the start of interval C, and a daily bag limit of two gags per person was implemented at the start of interval D. In interval E, recreational harvest was closed 10 months in 2011 and 8 months in 2012. Average annual discards as a percentage of total catch increased from a low of 29.4% during interval A, to 77.9% during interval B, 81.6% during interval C, and 90.4% during intervals D and E combined. Declines in total catch from 2005-2007 are associated with a large-scale episodic red tide bloom in 2005 (SEDAR 2009). Source for catch data: SEDAR 2013.

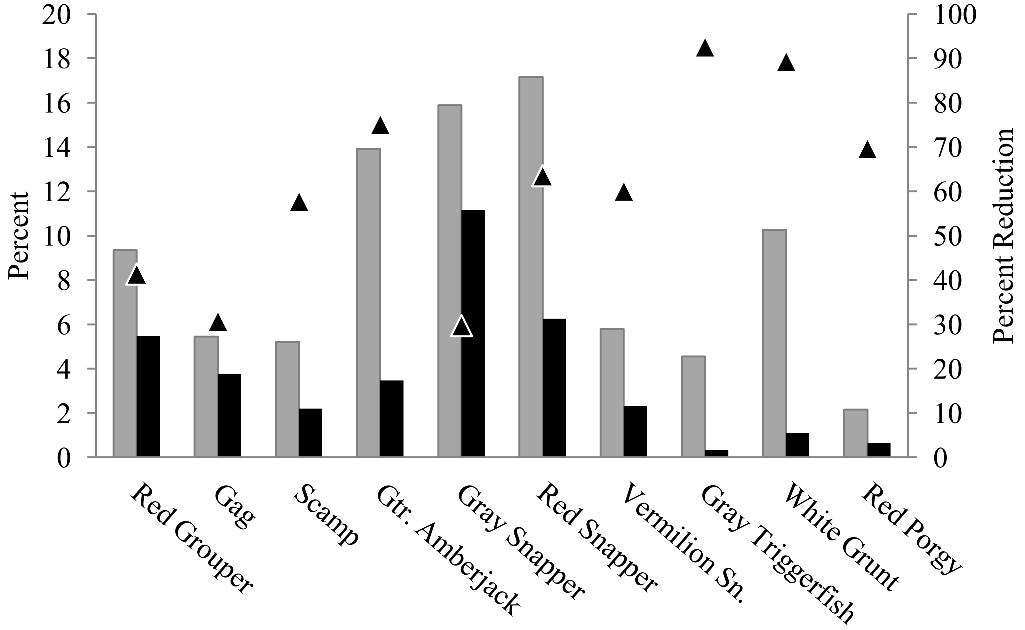

Figure 2. Percentage of reef fishes, by species, that were observed in a recreational hook-and-line fishery with potentially lethal hooking injuries when caught with circle hooks (black bars) and all other hook types (gray bars). Black triangles denote the percent reductions in injuries for fish caught with circle hooks compared to other hook types. Differences between hook types for gag, scamp and red porgy were not significant. From Sauls and Ayala (2012).

Data Needs for Stock Assessments

Stock assessments require accurate estimates of the magnitude, size distribution, and mortality rate of discards to accurately assess both total fishery removals and stock size. The total number of fish discarded (magnitude) and the portion of those discards that die (mortality) are equally important for measuring total removals from the population attributed to fishing mortality (F=harvest deaths + discard deaths). As an example, in the commercial trawl fishery for Atlantic cod in Canada, young year-classes discarded from the gear suffered high mortality rates but were apparently under-reported in catch data. In the absence of data on the magnitude or size distribution of discards, stock assessments interpreted declines in landings as an environmental effect on recruitment, when in fact F was much higher than estimated and eventually led to recruitment failure and collapse of the fishery (Myers et al., 1997). Information on the size distribution of discards is required for catch-at-age models and is another important data need that is often not available for use in stock assessments (Harley et al., 2000). Finally, when the magnitude and size distribution of discards is known with reasonable certainty, stock assessments still require a good estimation for the portion of discards that die (Dickey-Collas et al., 2007; Mesnil, 1996). When discard mortality is overestimated, there is a risk that in addition to overestimating F, stock size is also overestimated (Mesnil, 1996). Essentially, in a catch-at-age model, young fish in the discard portion that are assumed to die make up a portion of catches in later years, which means members of the year class may be counted more than once.

In order to estimate the portion of discards that contribute to total F, stock assessments have looked to a body of research that 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). 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 (Gale et al., 2013).

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, which may also result in increased regulatory discards, and to quantify actual reductions in discard mortalities attributed to conservation measures, such as the requirement to use circle hooks (Coggins et al., 2007; Cooke and Schramm, 2007; Sauls and Ayala, 2012). A method that is gaining increased interest specifically to evaluate survival of discards is conventional tagging studies. The advantages of tagging studies are that they measure survival under natural conditions, potential interactions between multiple stressors are measured intrinsically, latent mortality is included in survival estimates from mark-recapture models, and any potential increased mortality due to predation of impaired fish is not excluded, as it is in cage and laboratory studies. Mark-recapture models have been used extensively to estimate overall survival in open populations (Pine et al., 2003); however, such models are not useful for evaluating relationships between survival and explanatory variables (Burnham et al., 1987). Furthermore, many mark-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 mark-recapture models were also once thought to be robust to the assumption that all tagged fish within a study shared equal probabilities for recapture, but it has since been shown that variable encounter probabilities can introduce substantial bias in parameter estimates from mark-recapture models (Pledger et al., 2003).

Beginning in the 1980's, a new class of mark-recapture models, called survival effects models, was developed that could be used to identify factors that affect survival among different groups of tagged individuals (Burnham et al., 1987; Smith, 1991). Hueter et al. (2006) described a survival effects model that evaluated the relative survival 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 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 were used to calculate relative survival (S) as:

$$S = \mathrm{R_e}/\mathrm{R_u}, \qquad \text{Eq. 1}$$

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 was derived from a logistic model that predicts the proportions of recaptured fish from the exposed and unexposed groups. Equation 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, may be used to evaluate not just the occurrence of recapture events, but also the timing of those 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 also 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; Smith, 1991; Pollock et al., 1989). Survival analysis 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. If groups of individuals are disproportionately lost to the study over time, then covariates may need to be considered. For example, if tags are less likely to be noticed by anglers on fish that are below a minimum size limit for retention, then fish size may be a necessary covariate.

Approach

The Florida Fish and Wildlife Conservation Commission (FWC) placed fishery observers on for-hire vessels operating from the west coast of Florida to collect vital statistics on reef fishes caught and released during recreational hook-and-line fishing in the eastern Gulf of Mexico. For-hire vessels provide paid access to offshore fishing grounds with a professional captain and crew and include large party boats (also called headboats) that carry upwards of 100 individual passengers, and smaller charter vessels that cater to private fishing parties (typically 10 or less passengers). In the Gulf of Mexico region, anglers on for-hire vessels must abide by the same recreational harvest restrictions (e.g., size and bag limits, seasons, gear restrictions) as anglers on privately owned vessels. The objective of this analysis was to develop methods that may be used to rapidly assess the condition of reef fish discards (which were tagged prior to release) in the recreational hook-and-line fishery observed from for-hire vessels and develop a model that could control for potential covariates on both the occurrence and timing of recapture events so that relative survival of discards released in different conditions could be evaluated. Information derived from mark-recapture rates was then used to estimate overall discard mortality within the observed fishery.

Gags were tagged as they were encountered in the fishery year-round, over multiple years, and over a large geographic area, and for this study design 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 different regions of the west coast of Florida. For example, effort in the northwestern region of the state (termed 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, which varies annually. The Big Bend region (geographically, where Panhandle transitions to Peninsula) is located within a sparsely populated area of the state, and fishing effort is comparably low there year-round. Farther south in the western Peninsula region, the area surrounding Tampa Bay is a human population center and fishing effort in the adjacent Gulf of Mexico is highly dispersed across a longer fishing season and among low-relief natural-bottom habitats distributed across the broad, shallow West Florida Shelf. Fishing effort also potentially varied across time due to changes in the length of the recreational harvest season for gag 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 2010 Deepwater Horizon oil spill in the Gulf of Mexico. Fishing effort following this event 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 Gulf. 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.

CHAPTER 2: METHODS

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 cooperative research 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 (Figure 3). 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 hour) 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 on red snapper in area A and in a fourth region commonly referred to as Florida's Big Bend (area D in Figure 3). 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.

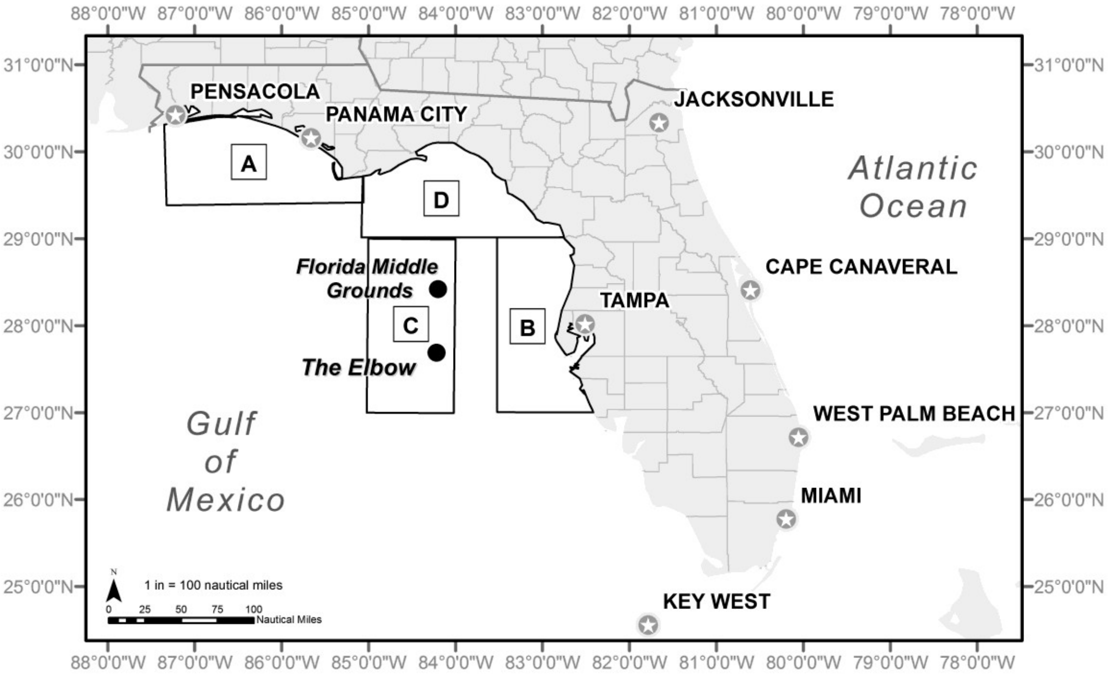

Figure 3. Regions within the study area include the Panhandle region (A), Tampa Bay nearshore region (B), Tampa Bay offshore region (C), and Big Bend region (D).

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 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 = initially disoriented and 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 (www.hallprint.com/plastic_dart_tags.php) 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.

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 mark-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.

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

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

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 in Table 1) specifically in response to catch-and-release events. To evaluate the timing and occurrence of recapture events among gags released in condition categories 2 and 3 relative to condition category 1, the PHREG procedure in SAS was used to construct a proportional hazards model. The proportional hazards model is a form of survival analysis first described by Cox (1972). The model was 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. The time-specific recapture reporting rate is described by the hazard function:

$$h_i(t) = \lim_{\Delta t \to 0} \frac{pr\,(t <= T < t+\Delta t \mid T>=t\,)}{\Delta t} \qquad \text{Eq. 2}$$

The numerator in equation 2 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.

Suppose now that each tagged fish in the population has a set of measurements (x_1 to x_k) associated with it. Then the hazard for an individual tagged fish to be reported at time t is explained by the proportional hazards regression model:

$$h_i(t|x_{i1}\ldots x_{ik}) = h_0(t) * \exp(\beta_1 x_{i1} + \ldots \beta_k x_{ik}), \qquad \text{Eq. 3}$$

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 in equation 3 works, consider a simple model with one variable x, where x=0 if a fish is released at the surface and submerges on its own and x=1 if the fish is unable to submerge and remains floating at the surface. Equation 3 reduces to:

$$h_i(t|x_{i1}) = h_0(t) \text{ when } x=0\text{, and} \qquad \text{Eq. 4}$$

$$h_i(t|x_{i1}) = h_0(t) * \exp(\beta) \text{ when } x=1 \qquad \text{Eq. 5}$$

The baseline hazard function in equation 4 describes the risk for individuals within the reference group to be reported as recaptured at time t, and exp(β) in equation 5 is the proportionate increase or decrease in that risk for individuals with characteristic x=1. Adding other covariates to this model controls for potential confounding effects on both the reference group and the treatment group.

The proportional hazards model is semi-parametric in that it makes no assumptions about the form of the hazard function. Rather, the main objective is to assess the parametric relationship between the time that individuals are reported as recaptures and the explanatory variables. Taking the log of both sides of equation 3, the predictors act additively on the hazard function, which responds linearly with β parameters:

$$\log h_i(t|x_{i1}\ldots x_{ik}) = \log h_0(t)+ \beta_1 x_{i1} + \ldots \beta_k x_{ik}, \qquad \text{Eq. 6}$$

The likelihood function is factored into two parts, one that includes both β and $h_0(t)$ that is not used, and one that does not include $h_0(t)$ and upon which partial likelihood is used to derive maximum likelihood estimates for β (Cox, 1972).

Still using the example with a single variable x, when the instantaneous rates of $h(t)$ for individuals in groups i and j are compared as a ratio (referred to as the hazard ratio), $h_0(t)$ cancels out to yield:

$$H = h_i(t)/h_j(t) = \exp(\beta x_i) / \exp(\beta x_j) = \exp\{\beta(x_i - x_j)\}, \qquad \text{Eq. 7}$$

When there are multiple variables measured for each individual, equation 7 becomes:

$$H = \exp\{\beta_1(x_{i1} - x_{j1}) + \ldots\ \beta_k(x_{ik} - x_{jk})\} \qquad \text{Eq. 8}$$

Thus, the hazard ratio for two treatment groups is an instantaneous rate that is interpreted much like the ratio described in equation 1, with the added feature of controlling for covariates not just on 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:

$$\mathrm{CI} = H * \exp\,(\pm Z_{1-\alpha/2} * \mathrm{s.e.}H), \qquad \text{Eq. 9}$$

The response variable 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 at the end of the study (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 (Figure 4). 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 (Figure 4), and time in the study was defined as the number of days from when individual fish were tagged until December 31, 2012, which was the end of the study for the purpose of this analysis. The proportional hazards model was stratified by year (explained below) and 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 and time of year (month) that fish were initially tagged and released; continuous variables for capture depth (meters) and size at original capture (mm midline length); and all possible interaction terms.

An important assumption of the proportional hazards model is that the underlying hazard functions among individuals vary proportionately with respect to time. In this study design, the recapture probability for tagged fish was expected to vary across years of entry due to variable fishing effort and species targeting in response to increased harvest restrictions (Figure 4), among other potential factors previously discussed. Annual differences in mark-recapture rates were not of direct interest for this analysis, and to adjust for this confounding effect the proportional hazards model was stratified by year using the STRATA statement in the PHREG procedure. Stratified analysis treats fish tagged in each year of the study as sub-populations, each with their own baseline hazard function. 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 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 survival effects 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.

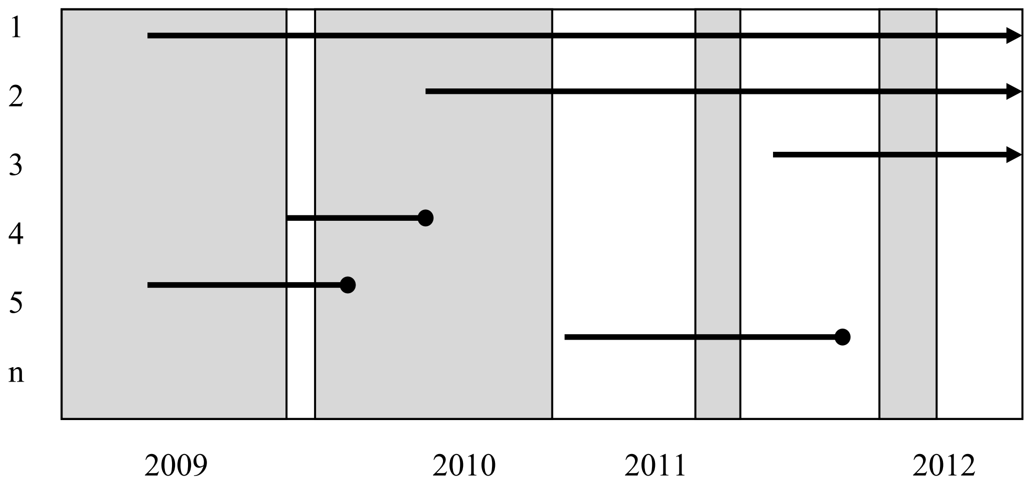

Figure 4. Schematic representation of staggered entry times and measured observation times for individual tagged fish. Individual 1 represents a fish tagged at the beginning of the study that was not reported as a recapture before the end of the study and the observation time was censored. Individuals 2 and 3 represent fish that were tagged later during the study and were censored after shorter observation times. For individuals 1, 2 and 3, all that is known is the time until first reported recapture exceeds censored time. Individuals 4, 5, and n represent fish tagged at different times during the study that were reported as recaptures for the first time after varied lengths of time at-large. These individuals are known to have survived the initial catch-and-release event. Shaded areas represent variable intervals of time over the duration of the study when the recreational harvest season for gag was open and at-large fish that survived the initial catch-and-release event were exposed to higher concentrations of fishing effort.

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 conditions 1, 2 and 3 ($N_{1,}$ $N_{2,}$ and $N_{3,}$ respectively) at each 10-meter depth interval (e.g., where d = 1–10 meters, 11–20 meters) 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 equation:

$$M_d = [1 - (N_1 * S_1 + N_2 * \hat{H}_2 + N_3 * \hat{H}_3) / (N_1 + N_2 + N_3)] * 100, \qquad \text{Eq. 10}$$

where S_1 is the absolute survival following catch-and-release for gags released in good condition (which is not truly known), and H_2 and H_3 are the estimated survival proportions for gags released in condition categories 2 and 3 (respectively), relative to gags released in condition category 1, 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 (category 1) 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 group, it is reasonable to assume that discard mortality in this treatment was minimal. 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 reviewed 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 (9 studies for 6 species, range 1.4–

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 equation 10 with lower and upper assumed values of 0.85 and 1.0, and substituting H_2 and H_3 in equation 10 with lower and upper 95% confidence limit values (calculated from equation 9).

CHAPTER 3: RESULTS

Among the four regions in the study area, a total of 3,954 live gag discards were observed from 439 randomly sampled trips and 79 hired charter trips (Table 2). The majority of gag discards were observed in the Tampa Bay nearshore region (n=256 trips). While a large portion of trips were conducted in the Panhandle region (n=218), the low number of gag discards observed with respect to the Tampa Bay nearshore region is reflective of their lower abundance in the northern Gulf. Only multi-day trips were conducted in the Tampa Bay offshore region and the smaller number of trips conducted in this region is reflective of reduced recreational fishing effort with increased distance from shore. In the Big Bend region, the low numbers of gags observed is due to the small number of paid charter trips (n=7), and no randomly sampled trips were conducted in this region.

When discards from the four regions were compared using a GLM model with Tukey post hoc tests, depth of capture was highly correlated with region ($F=1603$, $p<0.0001$, $R^2=0.549$; Table 2). Gags were caught from shallower depths in the Tampa Bay nearshore and Big Bend regions (mean 18.18 and 20.60 meters, respectively) and from deeper depths in the Panhandle and Tampa Bay offshore regions (mean 29.76 and 41.10 meters, respectively, and significantly different from each other and other regions at $\alpha \leq 0.05$). There were also significant differences in the mean size of gag discards among regions ($F=242$, $p<0.0001$, $R^2=0.156$; Table 2). Gags were smallest in the Tampa Bay nearshore region (mean 462.77 mm), of intermediate size in the adjacent Big Bend and Panhandle regions (532.24 and 522.65 mm, respectively and not significantly different from each other), and significantly larger in the Tampa Bay offshore region (584.98 mm).

Table 2. Characteristics of observed gag discards tagged and released by region. Means ± 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)	2,435 (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	-

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 3,954 live gag discards observed, the majority (77.8%) were released in good condition (condition category 1, Table 2). More than 90% of gags observed in the Tampa Bay nearshore region were released in good condition and, while fewer gags were observed in the Panhandle and Tampa Bay offshore regions, less than half were in good condition (Table 2). Similar to the Tampa Bay nearshore region, 92% of gags observed in the Big Bend region were released in good condition. More than half of gag discards in the two regions with deeper depths were vented before release (53% in the Panhandle and 61% in Tampa Bay offshore); whereas, more than 90% of fish submerged without the need for venting in the two shallower regions (Figure 5). The greatest percentage (12%) of gags released in poor condition (condition category 3) was also in the Tampa Bay offshore region (compared to <5.5% for other regions).

Release condition (all regions combined) was significantly correlated with length and depth at the time of initial capture and release ($F=642$, $p<0.0001$, $R^2=0.246$). Overall, gags released in condition 1 (good condition) were smaller and were caught from shallower depths than those released in conditions 2 and 3 (fair and poor conditions, Figure 6). Gags released in conditions 2 and 3 also had greater odds of exhibiting symptoms of barotrauma compared with those released in condition 1 (Table 3). A majority of gags in all release-condition categories exhibited a swollen bladder (range = 71.9% to 98.7%), which indicated at least mild barotrauma (Figure 7); however, those in fair and poor conditions were more likely to exhibit this symptom (Table 3). The presence of an everted stomach was less prevalent (Figure 7), and gags released in fair or poor condition were 3.81 and 2.98 times more likely, respectively, to exhibit this symptom than those 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 (Figure 7). When severe symptoms were present, fish were more likely to be in fair or poor condition (Table 3).

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.

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

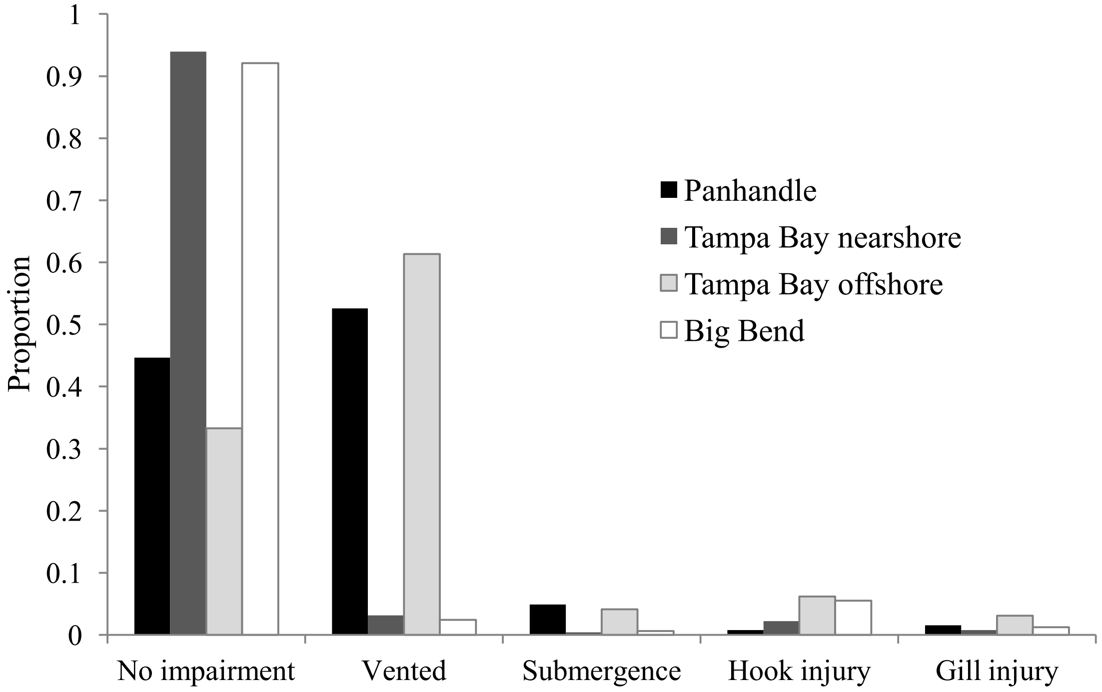

Figure 5. Proportion of gag discards by region that exhibited no impairment or that exhibited one or more impairments at the time of release. Individuals with more than one impairment symptom are included in multiple categories. No impairment means fish submerged immediately upon release without assistance 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.

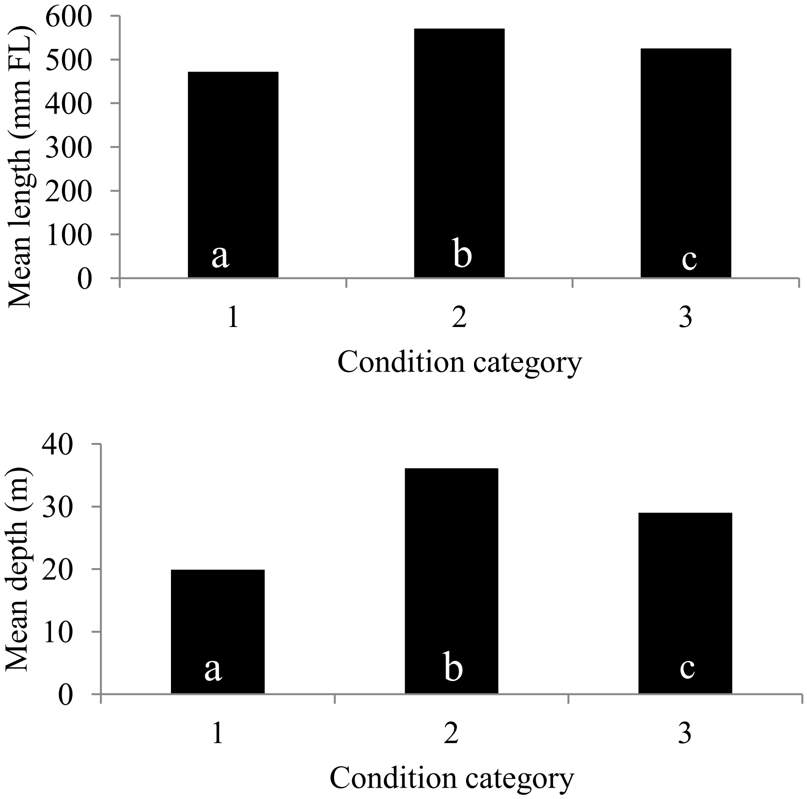

Figure 6. Mean length of gag discards (top) and mean depth of capture for gag discards by release condition category (Table 1). Different lowercase letters represent significant differences ($P < 0.05$) from GLM and Tukey post hoc tests.

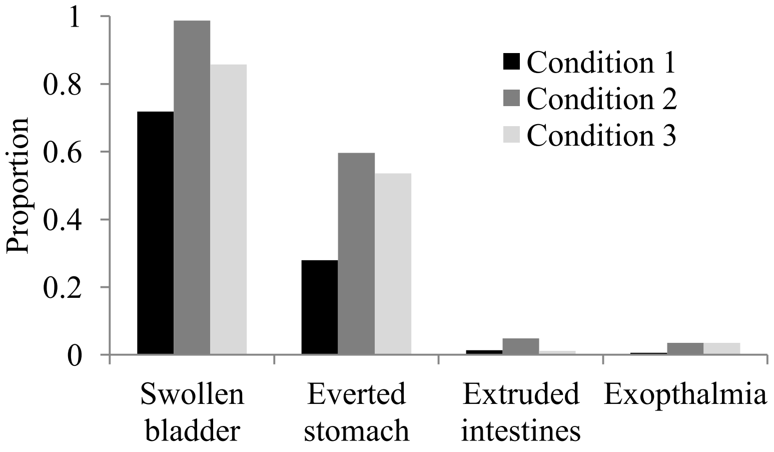

Figure 7. Proportion of gags observed with visible barotrauma by release condition category. The odds for observing each symptom among fish in each condition category are summarized in Table 3.

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). Recaptured fish were at large for a minimum of 2 days and a maximum of 782 days before the first reported recapture (Figure 8). 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). Fewer gags were tagged in the Big Bend region, particularly in fair and poor condition categories, and of the 10 recaptures reported none were from fish released in fair or poor condition; therefore, this region was excluded from the analysis for relative survival among treatment groups.

Relative Survival of Live Discards

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. Region was highly significant (Table 4) and confirmed the necessity to control for variable mark-recapture rates across the large geographic study area. When referenced against the Panhandle region, 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 region (Table 5). Depth of original capture and interactions between depth and other covariates were not significant. The release condition category was significant (Table 4) 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 condition, category 1 (Table 6). Fish in condition category 2 were 66.4% as likely to be recaptured as fish in condition category 1. Fish in poor condition, category 3, were 50.6% as likely to be recaptured as fish released in good condition, category 1. There was no significant difference in relative survival between fish in fair and poor condition categories 2 and 3 (Table 6).

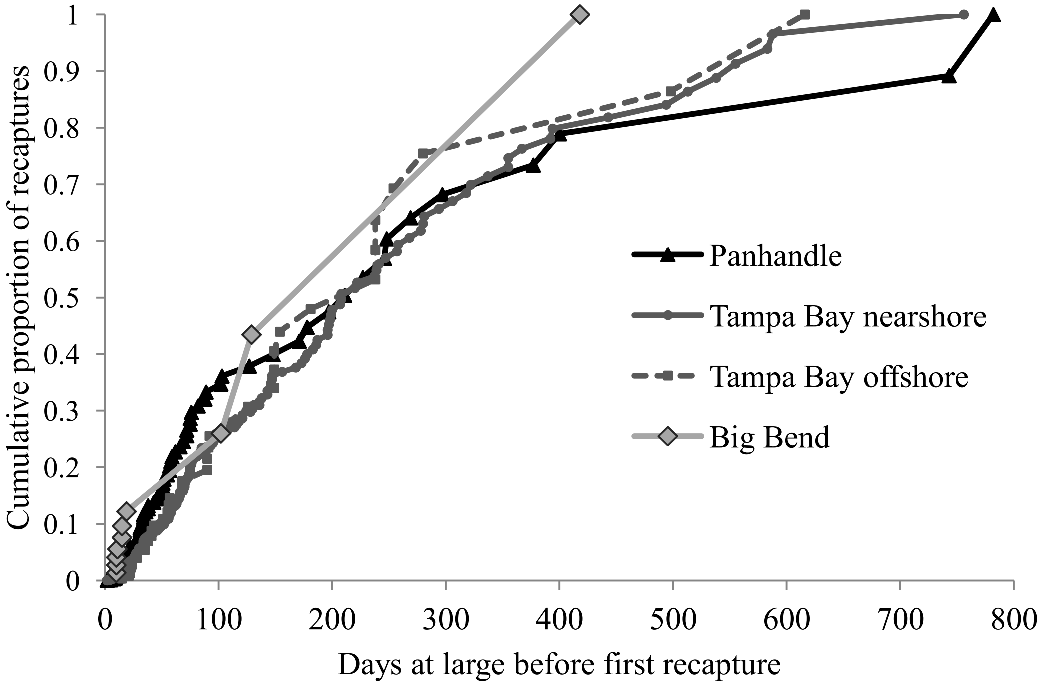

Figure 8. Days at large before first recapture expressed as the cumulative proportion of total at-large times for all recaptured fish, by region. The median time at large before first recapture was 34 days in the Panhandle region, 55 days in the Tampa Bay nearshore region, 68 days in the Tampa Bay offshore 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).

Table 4. Summary of the proportional-hazard model forward selection of independent variables on the number of days gags 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 (Figure 3). 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*year*length.

Effect entered	df	χ^2	*p*
Region	2	20.995	<0.0001
Month	11	20.895	0.035
Length	1	4.098	0.043
Length*month	11	24.301	0.012
Condition category	2	7.896	0.019

Table 5. Estimated hazard ratios (*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 (Table 4). Hazard ratios are significant when the 95% CI does not overlap 1.0.

Region	*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 (*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 (Table 4).

Condition category	*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	0.622	0.430

Overall Discard Mortality Estimates

Discard mortality over all gags observed within the recreational hook-and-line fishery was calculated at 10-meter depth intervals (Table 7). For the median survival value, at which 92.5% of gags observed in good condition were 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 meters. 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 meters to 35.6% (5.6–55.7%) at depths greater than 70 meters (Figure 9).

Table 7. Number of gags observed in condition categories 1, 2 and 3 (N_1 to N_3) by depth interval, and estimated overall discard mortality (M_d) expressed as percentage under varying assumptions of survival for gags in condition category 1 (S_1). Uncertainty around point estimates for 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 H_2 and H_3 from Table 6 and lower and upper assumed values of 0.850 and 1.000 for S_1 into equation 10. See also Figure 9.

				Percentage discard mortality (M_d)		
Depth (m)	N_1	N_2	N_3	$S_1 = 1.000$	$S_1 = 0.925$	$S_1 = 0.850$
1–10	216	1	6	1.48	8.74 (0.09, 16.75)	16.01
11–20	1,687	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

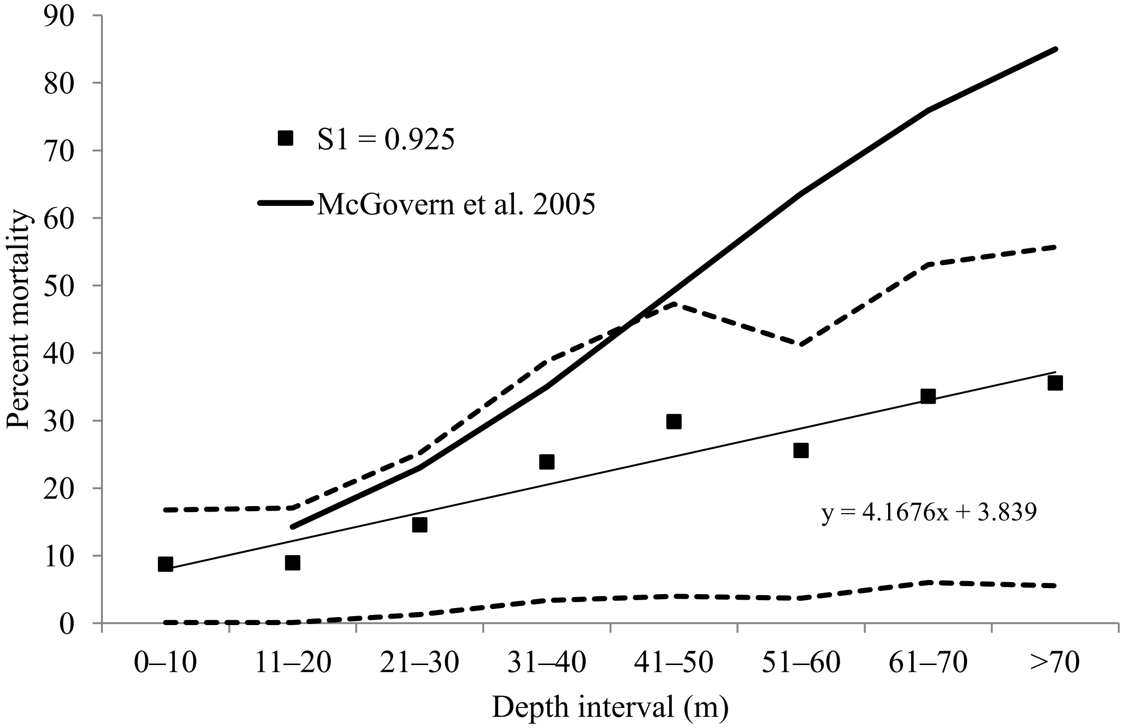

Figure 9. Overall estimated percentage mortality for gags observed, by 10-meter depth interval. Point estimates (squares) assume 92.5% survival of gags released in condition category 1 (S_1= 0.925), and the linear increase (light line) in point estimates with increased depth is significant ($p < 0.001$, $R^2 = 0.917$). 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 meters, and gags captured in depths >70 meters 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.

CHAPTER 4: CONCLUSIONS AND DISCUSSION

The detection of significant differences in relative survival between release condition categories under the highly variable conditions of capture, handling and release that fish experience within the recreational fishery was an unequivocal result. By collecting data on a variety of impairments and condition factors in the field, gags in the best condition could be distinguished, which allowed for meaningful comparisons with gags released in poorer condition. The proportional hazards model was also effective for controlling the effects of variable fishing effort across regions, years, and times of year. In conclusion, this study demonstrated the utility of a rapid method to assess the conditions of discards observed directly in a large-scale fishery so that variable degrees of exposure levels measured under true conditions and at appropriate spatial and temporal scales may be translated into overall estimates of discard mortalities.

Two factors contributed to the high degree of uncertainty surrounding estimates of overall discard mortality in this study. First, survival of fish released in good condition could not be compared to a true control, which was resolved by choosing an acceptable range of estimates for absolute survival and incorporating this range into upper and lower bounds of overall mortality estimates. Given the large magnitude of discards in this fishery and the fact that the majority of fish observed in the fishery were released in good condition, assumptions pertaining to this portion of total discards have a significant influence on overall estimated numbers of losses to discard mortality. In shallow water, where nearly 80% of fish in the control group were observed, overall estimated discard mortality was approximately 9% (range of uncertainty 0.09%

to 17.05%) at depths up to 20 meters and approximately 15% (1.30% to 25.21%) between 21 and 30 meters. This range is comparable to two other studies for gag. One published mark-recapture study estimated overall mortality to be 14.3% and 23% for gags released in depth intervals of 11–20 meters and 21–30 meters, respectively (McGovern et al. 2005; Figure 9). At shallower depths (mean 5.7 meters), another unpublished study reported 7.2% of gags (n=111) caught with hook-and-line gear suffered mortality when held in cages for 48 hours (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); however, the two studies provide an approximation for upper and lower bounds of overall discard mortality estimates at shallow depths. The cage estimate is potentially low because it excluded predation mortality whereas, the tagging study is considered an upper bound estimate for overall discard mortality because it included additional sources of natural mortality unrelated to catch-and-release. These bounds are supported by studies for other species which report overall discard mortality estimates in shallow depths that range between 1.4 and 14.4% (reviewed in SEDAR, 2013). The second source of uncertainty around overall discard mortality estimates is the large confidence intervals around estimates of relative survival for fish released in fair and poor condition. While fewer fish observed in the fishery were caught and released in depths greater than 30 meters, there was a wide band of uncertainty around estimates for overall discard mortality at these depths due to higher proportions of fish observed in fair and poor conditions. Known-fate studies, such as acoustic telemetry, may be useful to validate assumptions in this model pertaining to absolute survival for fish released in good condition, as well as estimates of relative survival for fish released in fair and poor conditions. However, care should be taken in such studies to ensure that stress and impairment related to attachment or implanting of acoustic tags does not result in additional mortality unrelated to catch-and-release events.

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, they were captured in relatively shallow depths and released in good condition, meaning they did not require venting in order to immediately submerge and 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 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 cannot be ruled out that these fish may have suffered greater mortality if they had not been vented and thus unable to re-submerge. The relationship between length and depth is likely related to habitat shifts farther offshore with increased size (Heppell et al., 2006), and it is possible that additional stress experienced by larger fish captured from deeper depths unrelated to the act of venting contributed to their reduced survival. For example, larger fish have a higher oxygen demand and may be more susceptible to reduced dissolved oxygen levels when released into warmer water at the surface (Gale et al., 2013). However, these results do lend support the recommendation that fish should be returned back to the water as quickly as possible without venting when the technique is not necessary for them to successfully re-submerge.

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. 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 two large-scale tagging studies controlled for the potential effect of variable fishing effort among regions within 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 meters 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 meters offshore versus 18.2 meters 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 vessel 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 meters) than in the Tampa Bay nearshore region, yet the highest overall mark-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. The band of uncertainty for estimates in this study was wide at depths >30 meters due to higher proportions of gags in fair or poor condition and the large confidence intervals around estimates of S_2 and S_3. However, 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 (Figure 9).

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 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 mark-recapture studies, this analysis demonstrated the importance of understanding and accounting for covariates on mark-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 mark-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 mark-recapture models.

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APPENDIX A: SAMPLE DATA AND SAS CODE

To illustrate how data were coded for the PROC PHREG procedure in SAS, a sample of thirty records from the full data set (>3,000 records) is provided in Table A1. Each line of data represents one individual tagged fish. The variable “recapture’ is dummy coded and equal to 1 for fish that were reported as recaptured, and 0 for fish that were not reported and were censored at the end of the observation period. The time interval between when a fish was tagged (tag_date) and first reported as a recapture (recap_date) can be calculated directly in SAS when dates are formatted as SAS dates. For fish that were not reported as recaptured at the time of this analysis, observation time was censored on December 31, 2012. The following statement is used in a data step to calculate the time interval for each recaptured or censored fish:

```
IF recapture=1 THEN time=recap_date-tag_date;
IF recapture=0 THEN time=MDY(12,31,2012)-tag_date;
```

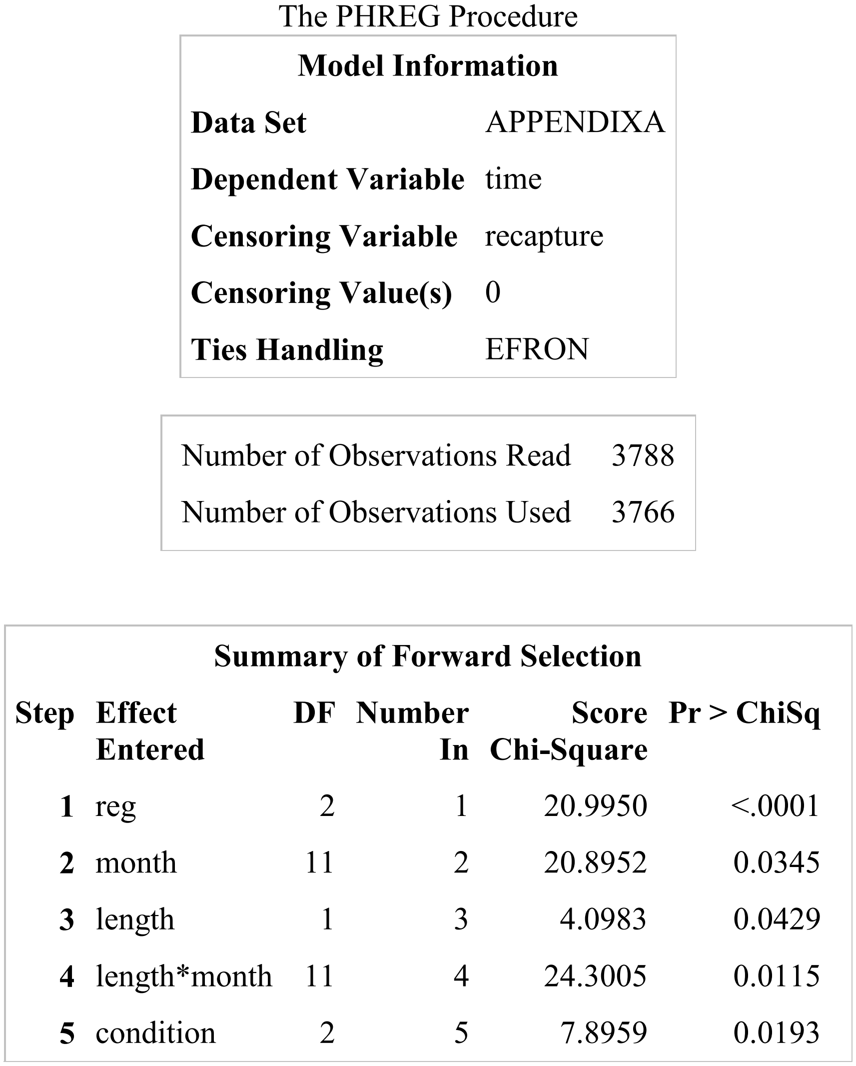
The PROC PHREG procedure includes a CLASS statement for categorical variables that are automatically converted to dummy codes by SAS. Continuous variables, such as fish length and capture depth, should not be included in the class statement. For each categorical variable in the CLASS statement, a reference group may also be specified in parenthesis. In the example below, fish in condition class 1 are specified so that condition classes 2 and 3 will be referenced against this group.

```
PROC PHREG data=<name of data set>;
        CLASS condition (ref='1') region (ref='PH') month;
        MODEL time*recapture(0) = condition region length depth month
        length*month length*depth depth*month length*depth*month
        /ties=efron selection=forward slentry=0.25;
        STRATA year;
        RUN;
```

The MODEL statement identifies 1) the variable that measures the interval for time at large (time), 2) the variable that identifies whether an individual fish was reported as recaptured or censored (recapture), and 3) the code that identifies which observations are censored (0). Covariates to be tested for inclusion in the model are listed in the MODEL statement after the equal sign, and may also include interaction terms (e.g. length*month). Options are also listed following a forward slash. In the example below, the option “ties=efron” tells SAS how to handle multiple records for recaptured fish with the same time interval measurement so that the partial likelihood can properly order tied observations. Several methods to handle ties are available in SAS, and efron is one preferred method because it is computationally precise (Allison, 2010). Defining a small unit of time for the interval calculation (i.e. number of days at large, as opposed to rounding to weeks or months) also helps to minimize the number of exact ties. The option for “selection” specifies how individual covariates are entered into the model and tested for significance. The forward selection procedure is specified in the example below, and other options include backward and stepwise procedures. The STRATA statement specifies that separate partial likelihoods should be calculated for fish tagged in each year of the study. Year is specified as a stratum due to differences in fishing effort that could cause the form of the baseline hazard function for each group of fish tagged to vary each year. Table A2 provides SAS output when the PROC PHREG procedure is run on the full data set.

Table A1. Sample data.

Recapture	Time	Region	Condition	Depth	Year	Month	Length
0	204	TBN	2	31	2012	06	610
0	649	TBN	1	13	2011	03	272
0	430	TBN	1	20	2011	10	452
0	1013	PH	1	30	2010	03	501
1	555	TBN	1	16	2011	01	422
0	80	PH	2	31	2012	10	540
0	396	TBN	1	18	2011	12	602
0	382	TBN	1	10	2011	12	602
0	57	TBN	1	9	2012	11	460
0	554	TBN	1	18	2011	06	472
1	58	TBN	1	25	2011	06	447
0	382	TBN	2	10	2011	12	343
0	830	TBN	1	17	2010	09	530
0	1061	TBN	1	21	2010	02	339
0	50	TBN	1	14	2012	11	581
1	60	TBN	1	20	2011	08	575
0	723	TBN	1	16	2011	01	382
0	938	TBN	1	18	2010	06	524
1	70	TBN	1	17	2010	01	415
0	977	TBN	1	14	2010	04	498
0	32	TBN	1	12	2012	11	410
0	7	TBN	1	15	2012	12	560
0	32	TBN	1	12	2012	11	381
0	681	PH	2	50	2011	02	670
0	394	TBN	1	13	2011	12	564
0	297	TBO	3	45	2012	03	574
0	1086	TBN	1	26	2010	01	456
0	762	TBN	1	14	2010	11	481
0	50	TBN	1	14	2012	11	420



The PHREG Procedure

Model Information	
Data Set	APPENDIXA
Dependent Variable	time
Censoring Variable	recapture
Censoring Value(s)	0
Ties Handling	EFRON

Number of Observations Read	3788
Number of Observations Used	3766

Summary of Forward Selection

Step	**Effect Entered**	**DF**	**Number In**	**Score Chi-Square**	**Pr > ChiSq**
1	reg	2	1	20.9950	<.0001
2	month	11	2	20.8952	0.0345
3	length	1	3	4.0983	0.0429
4	length*month	11	4	24.3005	0.0115
5	condition	2	5	7.8959	0.0193

Figure A1. SAS output showing model results using forward selection in the PHREG Procedure.

Table A2. SAS output showing maximum likelihood estimates from PHREG Procedure. The hazard ratio is the point estimate for relative recapture reporting rates for fish released in conditions 2 and 3 referenced against fish in condition 1 after controlling for covariates.

Parameter	**Class**	**DF**	**Parameter Estimate**	**Standard Error**	**Chi-Square**	**Pr > ChiSq**	**Hazard Ratio**
condition	**2**	1	-0.40878	0.17716	5.3242	0.0210	0.664
condition	**3**	1	-0.68165	0.33646	4.1046	0.0428	0.506
region	**TN**	1	-0.55506	0.15877	12.2213	0.0005	0.574
region	**TO**	1	-0.56422	0.20399	7.6506	0.0057	0.569
month	**01**	1	2.36256	1.38536	2.9083	0.0881	.
month	**02**	1	0.69051	1.16751	0.3498	0.5542	.
month	**03**	1	1.32270	1.19877	1.2174	0.2699	.
month	**04**	1	1.98394	1.08455	3.3463	0.0674	.
month	**05**	1	1.46332	1.11127	1.7340	0.1879	.
month	**06**	1	-0.21813	1.19195	0.0335	0.8548	.
month	**07**	1	-2.03327	1.58216	1.6515	0.1988	.
month	**08**	1	0.08726	1.97691	0.0019	0.9648	.
month	**09**	1	-1.74742	1.60350	1.1876	0.2758	.
month	**10**	1	-5.00863	2.23191	5.0360	0.0248	.
month	**11**	1	2.09385	1.25424	2.7870	0.0950	.
length		1	0.00212	0.00172	1.5146	0.2184	.
length*month	**01**	1	-0.00493	0.00299	2.7203	0.0991	.
length*month	**02**	1	-0.0002561	0.00223	0.0132	0.9086	.
length*month	**03**	1	-0.00141	0.00231	0.3748	0.5404	.
length*month	**04**	1	-0.00238	0.00213	1.2490	0.2637	.
length*month	**05**	1	-0.00161	0.00219	0.5434	0.4610	.
length*month	**06**	1	0.00147	0.00222	0.4368	0.5087	.
length*month	**07**	1	0.00380	0.00282	1.8172	0.1777	.
length*month	**08**	1	0.00215	0.00411	0.2725	0.6017	.
length*month	**09**	1	0.00460	0.00316	2.1143	0.1459	.
length*month	**10**	1	0.01164	0.00452	6.6269	0.0100	.
length*month	**11**	1	-0.00341	0.00255	1.7809	0.1820	.

APPENDIX B: RIGHTS AND PERMISSIONS

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