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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. Changes in fishing effort following the Deepwater Horizon event during 2010 in the Gulf of Mexico and drastically reduced recreational harvest seasons for gag during 2011 and 2012 were also 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 to compare 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 3,832 gags were observed in this study and the majority (77.79%) were released in good condition (condition category 1), defined as fish that immediately submerged without assistance from venting and did not suffer internal injuries from embedded hooks or visible damage to the gills. However, compared to gags caught in shallower depths, a higher proportion of gags caught-and-released from depths deeper than 30 meters were in fair or poor condition. After controlling for variable mark-recapture rates among regions and across months and years when tagged fish were initially captured and released within the recreational fishery, relative survival was significantly reduced for gags released in fair and poor condition. Gags in fair and poor condition were only 69.1% and 46.1% as likely to be recaptured, respectively, compared to gags released in good condition.

Key Words: Gag *Mycteroperca microlepis*, proportional hazards model, discard mortality, mark-recapture, recreational fishery

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 highest 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 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), and 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 harvested and released fish), down from 2.2 to 4.5 million gags caught annually 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 only during February and March to protect gag spawning aggregations. However, the gag stock in the Gulf of Mexico was classified as overfished and undergoing overfishing in 2009, and since 2011 recreational harvest has been closed for a majority of months to recover the stock. Consequently, approximately 90% of gag 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, among other factors (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 single factors, such as hook injury or barotraumas, often under experimental conditions, and results vary among studies. In addition, many available studies do not measure latent mortality and provide 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* 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). 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. However, models developed for tag-recapture data that were designed to estimate population parameters are not useful for evaluating relationships between survival and explanatory variables (Burnham et al., 1987). Furthermore, many tag-recapture models require that individuals are tagged and recovered during discrete sampling events, which is not always possible, particularly for *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 share equal probabilities for recapture; however, it has since been shown that variable encounter probabilities can introduce substantial bias in parameter estimates for 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 used in a commercial fishery. Each tagged fish was assigned to one of several treatment groups based on a measured risk for reduced survival, which for this 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

$$S = R_e/R_u, \qquad (1)$$

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. Equation 1 assumes that all tagged fish have approximately equal catchabilities and are subject to equal amounts 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. The logistic model may also be generalized to include covariates that influence the encounter probabilities 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, and the method has been applied widely in biomedical research to measure, for example, the influence of variable exposure levels on time until death or 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, as 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 is known. Provided that time until first recapture and time at-large without recapture for any individual in the study are independent, then individuals that do not experience a recapture event may be included in the analysis as right-censored observations, where the observation time is measured as the time between when a subject entered into the study until the time it was either 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 over wintered above damns (Lowther and Skalski, 1997). If it may be assumed that loss to a study over time affects all individuals the same, 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 from 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 throughout the year over multiple years over a large geographic area, it was necessary to control for potential covariates on recapture rates for fish tagged in different regions, different years, and different times of year. Fishing effort is variable among regions within the geographic area of this study. Effort in the panhandle region is highest during 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 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 event 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 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 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 to 100 miles offshore (Figure 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 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 of red snapper, *Lutjanus campechanus,* in area A and a fourth region commonly referred to as Florida's "Big Bend" (area D in Figure 1). The purpose of the hired charter trips was to tag and release red snapper caught using recreational fishing methods. Gags that were 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 March through May from 2010 to 2012.

During each randomly sampled recreational trip or hired charter trip, one to 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) the 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, and/or exopthalmia), 5) whether the fish was vented by the mate or the observer to reduce buoyancy from barotrauma prior to release (observers only 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 5) 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 reward, in the form of t-shirts, was offered to anglers 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 when tagged fish were encountered and returned to FWC. 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 Description of the data

Immediate mortality was calculated as the percent of all gag that were caught (and not harvested) with a release condition of either "dead" or "preyed". This percentage included gag that were released without a tag because they were dead on retrieval (usually attacked by a predator during ascent) and gag 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.

2.3 Data modeling

To evaluate the timing and occurrence of recapture events among gag 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 that was first described by Cox (1972). It is a regression model that estimates the hazard (h) for an individual i to experience an event (such as recapture) at time t as the product of:

$$h_i(t) = \lambda_0(t) * e^u \qquad (2)$$

Where $\lambda_0(t)$ is the baseline hazard function for an individual when all covariates equal 0; and u is a linear function of the covariates. When the hazards for two individuals are compared as a ratio, $\lambda_0(t)$ cancels out 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 similar to the rate ratio described in equation 1, but with the added feature of controlling for covariates on both the occurrence and the timing of recapture events within and among treatment groups. Akaike's information criterion (AIC) values based on partial likelihood of u in equation 2 reported in SAS output were used along with the forward selection procedure to select among potential covariates for the timing of recapture events. Timing of each recapture event was defined as the number of days from when an individual fish was tagged and released until the first reported recapture. Once a fish was recaptured the first time, survival was confirmed and observation times for subsequent recapture events were not included in the analysis. Fish that were not 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 for the purpose of this analysis. Condition category was an independent class variable in the proportional hazard model, and control variables tested include class variables for the 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. Covariates were also tested for significant interactions with time at-large for tagged fish, which would indicate a violation of the assumption that hazards for recapture are not proportional across time. This was controlled for by specifying groups to stratify the model by in the PHREG procedure, so that separate partial likelihood functions were constructed for each homogeneous group and then multiplied to obtain parameter estimates that maximize the function. Assumptions made by Hueter et al. (2006) that also apply to this model were that other sources of mortality unrelated to the catch-and-release event 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 for this model were 1) fish were encountered randomly, and the probability that an individual did not recover from the catch-and-release event was not influenced by the entry time into the study; and 2) an individual that was censored at the end of the study after t days at-large had the same probability for recapture at time t+n as all other individuals released in the same condition.

2.4 Discard mortality estimates

Numbers of observed gags released in good, fair and poor condition categories (N_1, N_2 and N_3) were summed by 10 meter depth interval (0-10 meters, 11-20 meters, etc.). Mortality, expressed as a percentage, was calculated for depth interval d as:

$$M_d = [\ 1 - \sum(N_1{*}S_1 + N_2{*}S_2 + N_3{*}S_3) / \sum(N_1 + N_2 + N_3)\ ] * 100 \qquad (3)$$

Where S_1 is the assumed proportion of observed gags released in good condition that survived, and S_2 and S_3 are the model-derived hazard ratios for proportional survival of gags released in fair and poor condition relative to gags released in good condition. Percent mortality for each depth interval was calculated separately under four assumptions for gags released in good condition: 100% survival (S_1=1.0), 90% survival (S_1=0.9), 80% survival (S_1=0.8) and 70% survival (S_1=0.7).

3. Results

3.1 Description of discards

Only eleven gag that were not retained by anglers suffered immediate mortality, which was a small percentage (<1.0%) of the total discards observed. Of the 3,832 live gag discards observed, the majority (77.79%) were released in good condition (condition category 1); however, 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 Tampa Bay nearshore region (Table 2). Only seven trips were conducted in the Big Bend region and 92% of gags observed in this region were in good condition. Gag discards from the Tampa Bay nearshore region were significantly smaller in size, and gag discards in the Panhandle and Tampa Bay offshore regions were captured in deeper depths (28.36 and 41.97, meters respectively) compared to the other regions (18.39 and 17.65 meters, Table 2). Just over half (53%) of gag discards in the Panhandle region and 61% of gag discards in the Tampa Bay offshore region were vented before release; which is in contrast to the other two regions, where more than 90% of fish were released in good condition without the need for venting (Figure 2). The highest percentage (11.98%) of gags released in poor condition (condition category 3) was also in the

Tampa Bay offshore region (compared to <5.5% in other regions). The total number of gags observed in the Big Bend was low because fewer trips were conducted in this region (Table 2).

When comparing observations for different release conditions across all regions, gags released in good condition were significantly smaller and were caught from significantly shallower depths than fish released in fair condition (Figure 3). Gags released in fair and poor condition have significantly higher odds for exhibiting symptoms of exposure to 9arotraumas compared to gags 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 exposure to barotraumas (Figure 4). The presence of an everted stomach was recorded if the stomach was visibly protruding through the esophagus into the buccal cavity. Stomach eversion was less prevalent in fish released in good condition (27.9%) compared to fish released in fair and poor conditions (59.6% and 53.6%, respectively, Figure 4). Symptoms of more severe barotruama exposure, including extruded intestines and exopthalmia, were rare (<5.0%) for gags observed in all release conditions.

3.2 Proportional Hazards Model

Before covariates were tested for inclusion in the proportional hazards model, three variables were tested for potential significant correlations (alpha$\leq$0.05) with time at large. Significant correlation indicates that the hazard functions among groups of fish (e.g. fish tagged among regions or among time periods within the study) do not behave proportionally with respect to each other over time, which would violate an important assumption of the proportional hazards model. The region where fish were tagged was significantly correlated with time at-large (Wilcoxan test of equality, χ^2=19.963, p=0.0003). Recaptured fish were at-large for a minimum of 2 days and a maximum of 782 days before the first reported recapture event (Figure 5). Recaptured fish were at-large for longer durations in the Tampa Bay nearshore and offshore regions (median 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 duration (median=15 days). Once the model was stratified by region, month and year were not significantly correlated with time at-large and could be entered as control variables in the model, along with capture depth and fish size at time of original capture and associated interaction terms. Variables selected during the forward selection procedure are summarized in Table 4, and significant covariates include month and year that 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. The forward selection procedure ended after the interaction term between year and month was entered in the model. Depth of original capture and interactions between depth and other covariates were not significant. The condition category of tagged fish was significant (χ^2=6.723 and p=0.0347) 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 5). Fish in condition category 2 were only 69.1% as likely to be recaptured as fish in condition category 1. Fish in poor condition, category 3, were only 46.1% 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 5).

3.3 Discard mortality estimates

Overall mortality expressed as a percentage was calculated by applying the hazard ratio point estimates from the proportional hazards model (Table 5) to the numbers of fish observed in fair and poor condition at 10 meter depth intervals (Table 6). Assuming that all gags observed in good condition survived catch-and-release (S_1=1.0), the overall estimated mortality rate for gags was less than 3% in shallow depths up to 20 meters, increased to 9% in depths 21-30 meters, and exceeded 20% only in depths deeper than 30 meters (Figure 6). Assuming a 10% to 20% reduction in survival for gags released in good condition (S_1=0.9 and 0.8), overall mortality exceeded 30% in the deepest depths. Mortality exceeded 30% across all depths when S_1=0.7.

4. Conclusions and Discussion

The results of this analysis provide some important conclusions that are informative for survival of discards in the recreational hook-and-line fishery. Perhaps most importantly, in the region where the majority of gags were encountered, gags were captured in relatively shallow depths and discarded in good condition at the time of release, 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. However, in regions where gags were caught in significantly deeper depths, discarded fish were in relatively poorer condition. For gags that were tagged and released in fair or poor condition, relative survival was significantly reduced when compared to gags that were released in good condition. The result that fish in fair condition suffer increased mortality compared to unvented fish in good condition should not be interpreted as a negative effect of venting on survival, since it is not possible from this observational study to tease apart the cause and effect relationship between venting and survival. 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 were not vented and unable to re-submerge. Immediate mortality, which included predation of hooked fish and fish released at the surface, was very low (<1%) and is similar to another published study that reported predation mortality of 1.3% observed from hooked fish and fish released at the surface (Overton et al., 2008).

This was an observational study that measured true conditions experienced by fish captured and released within the recreational 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 less optimum conditions. However, this analysis could not compare fish released in this study to a true control, since fish had to be captured and handled in order to be tagged. For this study, predation of displaced gags as they swim through the water column to return to the bottom is accounted for, but only for gags released in fair and poor conditions relative to gags released in good condition. The majority of gags (77.79%) were released in good condition and the percentage of these fish that were not recaptured due to predation mortality during descent is unknown. One other published tag-recapture study estimated mortality for gags released in shallow depths <21 meters at 14.2% (see Figure 6). No other published studies reported discard mortality specifically for shallow depths. In this study, over 95% of gags captured in shallow depths of 20 meters or less, where barotrauma should not be a major factor, were in good condition and catch and release mortality was estimated to be less than 3%. This estimate includes all potential sources of mortality for fish released in fair and poor conditions, including hooking injuries and predation, but does not account for predation of fish that were released in good condition (without hooking injuries). Assuming only 90% survival for gags released in good condition results in a disproportionately larger increase in overall mortality in shallow depths. For example, in capture depths of 11-20 meters, overall mortality is increased by 50% (from 1.92% to 11.52%). However, because the proportion of gags caught in good condition decreases with increased depth, the assumption regarding survival of fish in condition category 1 has less influence on overall mortality estimates at deeper depths (Figure 6). When survival of category 1 fish is assumed to be 0.8 or less, overall mortality in shallow depths begins to approach percentages in deeper depths, which is unlikely given that gags captured in deeper depths are exposed to longer retrieval and fight times, experience larger pressure and temperature changes, and must swim greater distances through the water column to return to bottom habitats.

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 controlling for covariates on tag-recapture rates before interpreting results. It was expected during the design of this study that variable fishing pressures would influence encounter rates among regions. However, changes in fishing regulations over the course of this study were not anticipated. Prior to 2011, recreational harvest was open during most months of the year; whereas, recreational harvest of legal-sized gag from federal waters was restricted to September 16 - November 15 during 2011, and July 1 - October 31 during 2012. Fish tagged and released just prior to the opening of a recreational season may be encountered after a shorter time at large, compared to fish tagged at other times of the year, due to an increase in targeted fishing effort. Therefore, it was important to control for the month and year that fish were tagged and released during this study. Examining interactions of covariates also helped interpret the combined effects of variable closed seasons with a minimum size limit, which remained unchanged during this study. The hazard ratio for length in this model was 1.132, which means that for each 100 mm increase in the size of fish at the time they were tagged, the hazard for recapture increased by 13.2%. This result was counter-intuitive, given that fish in good condition were significantly smaller compared to fish in fair and poor conditions. However, 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-sized gag 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-sized gag may be noticed less often during months when harvest is closed. Since sub-legal sized fish must be released year-round, tags may not be noticed or 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.

Two other published tag-recapture studies for gag and other grouper species cite reduced recapture rates with increasing depth as evidence of increased discard mortality, presumably due to barotrauma at deeper depths. Wilson and Burns (1996) reported tag-recapture percentages for gag, scamp (*M. phenax*) and red grouper (*Epinephelus morio*) tagged adjacent to the Gulf of Mexico coast of Florida (between 26 and 30 degrees latitude) during the years 1990-1994; and McGovern et al. (2005) reported tag-recapture percentages and estimated mortality percentages for gags tagged in the Atlantic Ocean between North Carolina and the Florida Keys during the years 1995-1998. While there were few changes in fishing regulations during the 1990's that would have effected fishing pressure across years, neither of these studies controlled for the potential effect of variable fishing effort among regions in the respective geographic areas when analyzing results. In the McGovern et al. (2005) study, 81% of gag were tagged during trips in South Carolina; however, the authors noted that recapture percentages were higher off Florida and attributed this observation to the fact that gag spawning aggregations at depths of 49-91 m are more accessible to fishermen in this portion of the study area due to the narrow continental shelf. This then begs the question whether reduced recapture rates in deeper depths may be explained, at least in part, by comparatively less fishing effort offshore in the region where the majority of fish were tagged? The results from this study also indicate that discard mortality increases with increased depth; however, in contrast to McGovern's model, the rate of increasing mortality slows after 40 meters and does not appear to be exponential in nature (Figure 6). Rather, the relationship between depth and proportional mortality in this study more resembles the lower range of the RAMP curve described by Davis (2010), which demonstrated a consistent sigmoid relationship between proportional mortality and reflex impairment across a gradient of measured stress factors for multiple species.

Overall recapture percentages for gag tagged in the two areas adjacent to Tampa Bay were slightly higher in the offshore region (8.06%) compared to the inshore region (6.64%), even though fishing took place at much deeper depths (mean=41.97 meters offshore versus 17.65 meters nearshore) and only 33% of gags were in the best condition category (compared to 94% nearshore). This can be attributed to the exceptional cooperation by the small number of headboat operators that exclusively offer multi-day 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, less than half (45%) of gags observed were released in the best condition and fishing also took place in relatively deeper depths (mean=28.36 meters) when compared to the Tampa Bay nearshore region, yet the highest overall tag-recapture percentage (13.8%) was from this region. Given that the shallow west Florida continental shelf is an important staging area for sub-adult gags before they migrate offshore (Koenig and Coleman, 1998; Switzer et al., 2012), sub-adult gags are highly abundant and vulnerable to the recreational fishery nearshore off the Florida peninsula (as evidenced by this study), and the highest concentration of recreational fishing effort in the Gulf of Mexico is near shore along the west coast of Florida (Hanson and Sauls, 2011), erroneously interpreting lower recapture percentages in the nearshore Tampa Bay region as an indication that fish suffer higher discard mortality when captured in shallower depths would have profound implications for fisheries management and stock assessments. Another study recently published by Burns and Froeschke (2012) based on tag recapture rates for fish tagged in both the Gulf of Mexico and the south Atlantic concluded that red snapper have lower survival and red grouper have higher survival when they are caught with circle versus J hooks; however, controlling for the effects of the region where fish were tagged and released may have yielded different results. In conclusion, it is important that researchers are 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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Table 1. Description of release condition categories for gag that were 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 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.

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 (%)	291 (44.6)	2,378 (93.9)	161 (33.26)	151 (92.1)
Condition 2 (%)	334 (51.2)	80 (3.2)	265 (54.75)	4 (2.4)
Condition 3 (%)	27 (4.1)	74 (2.9)	58 (11.98)	9 (5.5)
Numbers of fish recaptured:				
Condition 1 (% tagged)	46 (15.8)	218 (9.2)	15 (9.3)	10 (6.6)
Condition 2 (% tagged)	41 (12.3)	6 (7.5)	22 (8.3)	0
Condition 3 (% tagged)	3 (11.1)	4 (5.4)	2 (3.4)	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)	28.36 ± 9.0 (a)	17.65 ± 7.0 (b)	41.97 ± 7.0 (c)	18.39 ± 4.0 (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 the odds are 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)

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 being recaptured. The model was stratified by region (Figure 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*year*length.

Effect entered	df	χ^2	*p*	AIC after inclusion
Month	11	20.009	0.0452	5056.298
Length	1	2.735	0.0982	5055.581
Length*month	11	24.484	0.0108	5053.277
Condition category	2	6.723	0.0347	5049.955
Year	3	8.308	0.0401	5047.732
Year*month	28	39.551	0.0725	5062.278

Table 5. The proportional hazard ratio (95% CI) for recapture for fish in condition categories 2 and 3 referenced against fish in category 1, after controlling for the effect of covariates on recapture rates. Covariates are listed in Table 4. Hazard ratios are significant when the 95% CI does not overlap 1.0.

Condition category	Hazard ratio	χ^2	*p*
2 vs. 1	0.691 (0.482, 0.991)	4.047	0.044
3 vs. 1	0.461 (0.227, 0.936)	4.598	0.032
2 vs. 3	1.498 (0.722, 3.108)	1.177	0.278

Table 6. Numbers of gags observed in condition categories 1, 2, and 3 by depth interval and estimated mortality expressed as percentages. Mortality was calculated using proportional hazard ratios of 0.691 for fish in condition 2 and 0.461 for fish in condition 3, under varying assumptions of proportional survival for gags in condition 1 (S_1).

	Condition category			Percent mortality			
Depth range (m)	1	2	3	S_1=1.0	S_1=0.9	S_1=0.8	S_1=0.7
0-10	279	10	8	2.49	11.89	21.28	30.67
11-20	1,596	18	49	1.92	11.52	21.12	30.71
21-30	841	247	47	8.96	16.37	23.78	31.19
31-40	172	256	35	21.16	24.87	28.59	32.30
41-50	35	84	17	25.82	28.40	30.97	33.54
51-60	51	64	10	20.13	24.21	28.29	32.37
61-90	7	4	6	26.29	30.41	34.53	38.65

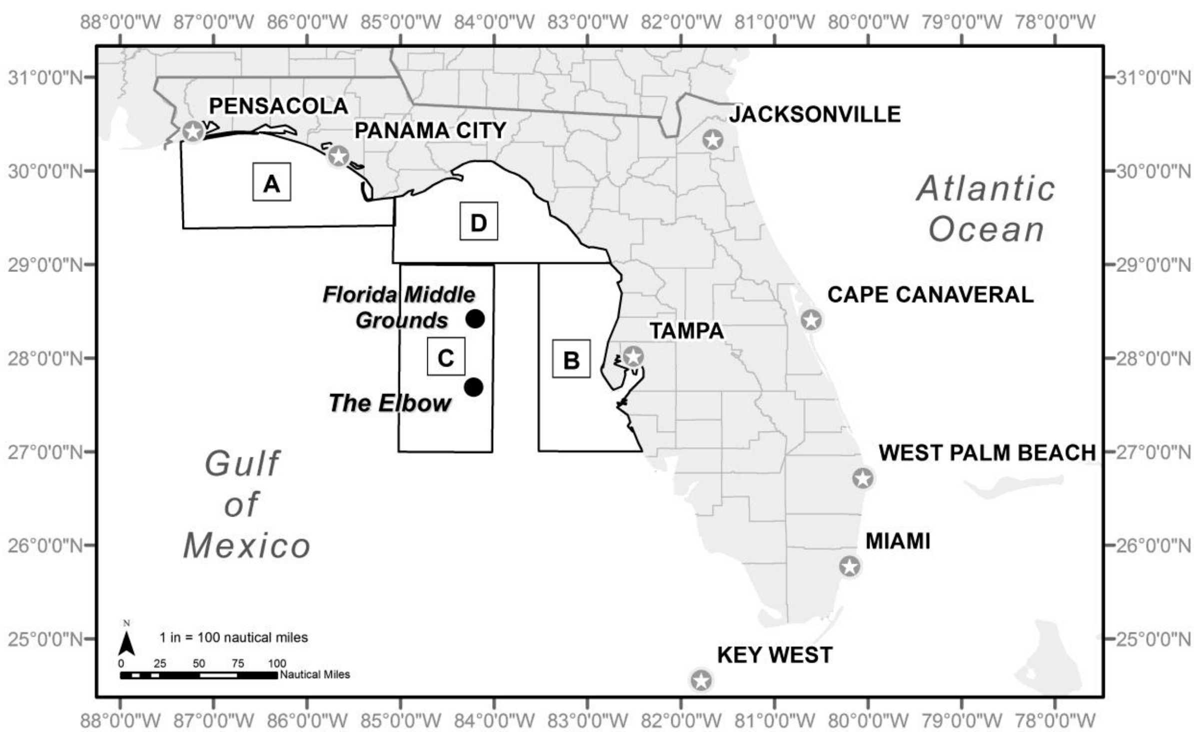

Figure 1. Regions within the study area include the Panhandle region (A), Tampa Bay nearshore region (B), Tampa Bay offshore region (C), and Big Bend region (D).

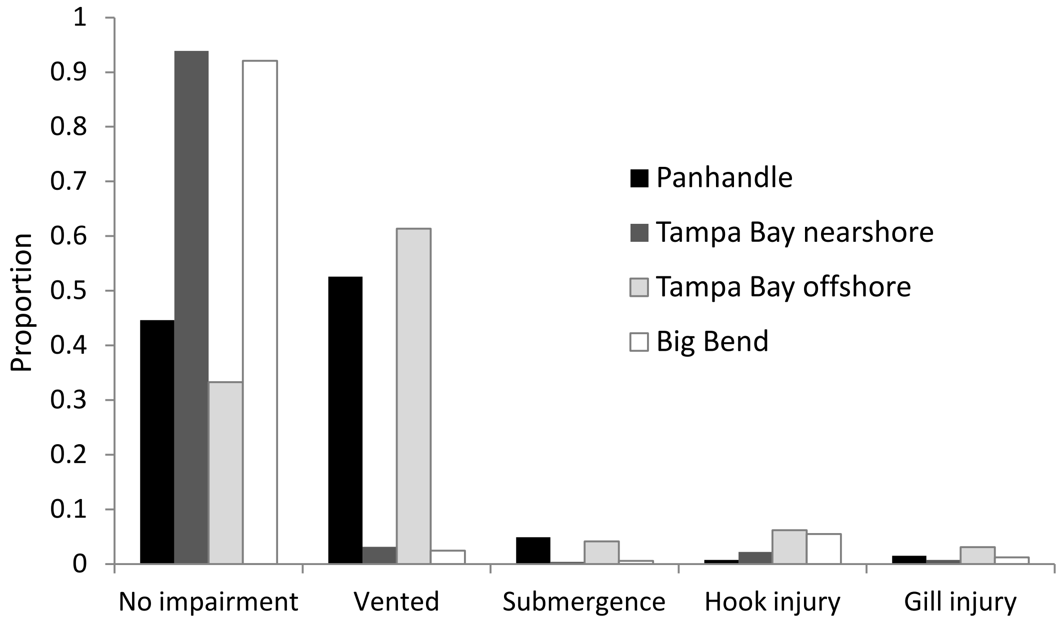

Figure 2. Proportion of gag discards by region that exhibited no impairment or that exhibited one or more impairments at the time of release (individuals with more than one impairment symptom are included in multiple categories). No impairment means fish submerged immediately upon release without assistance from venting and did not suffer hook or gill injuries. Venting means the swim bladder was deflated or the stomach was punctured before it was released. Submergence means a fish did not submerge immediately or was floating at the time of release. 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.

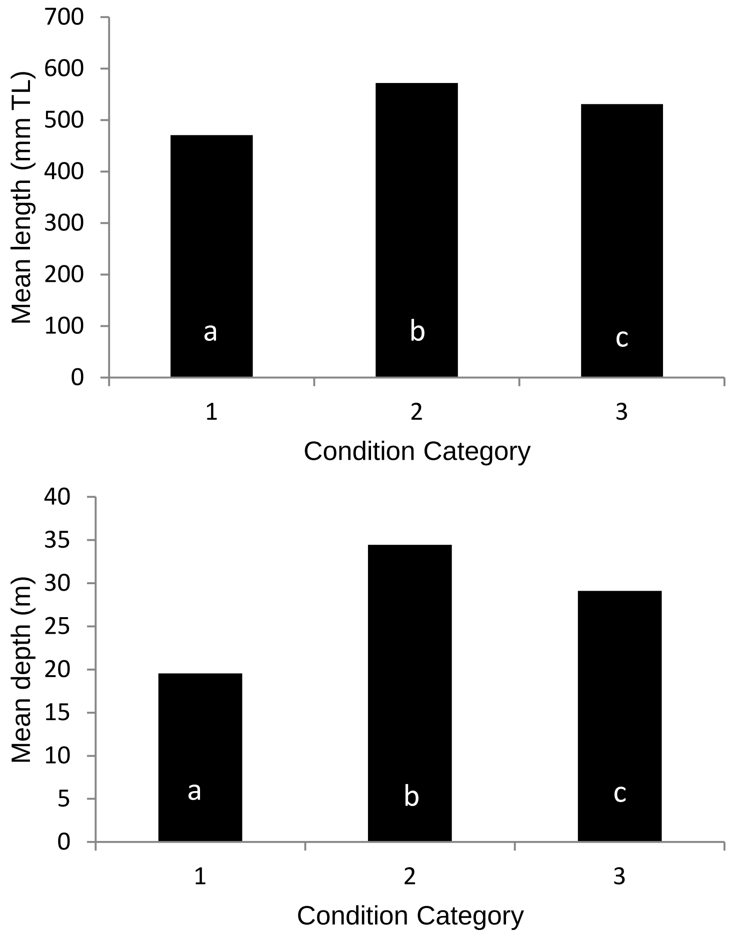

Figure 3. Mean length of gag discards (top) and mean depth of capture for gag discards by release condition category (Table 1). Different lowercase letters represent significant differences (P < 0.05) from GLM and Tukey post hoc tests.

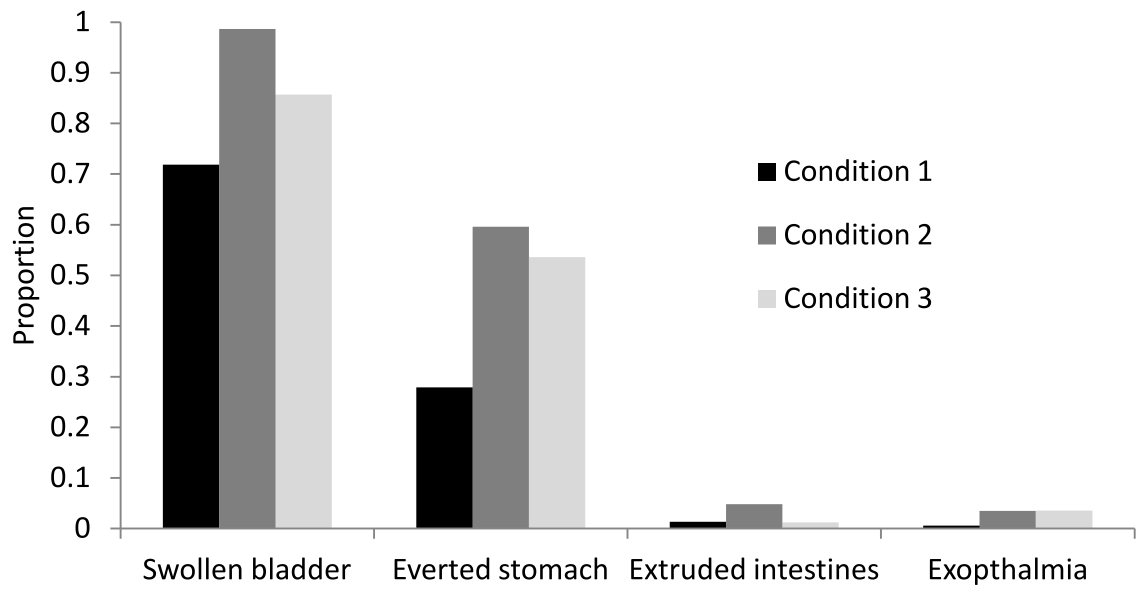

Figure 4. Proportion of gags observed with visible signs of barotrauma by release condition category. The odds for observing each symptom among fish in each condition category are summarized in Table 3.

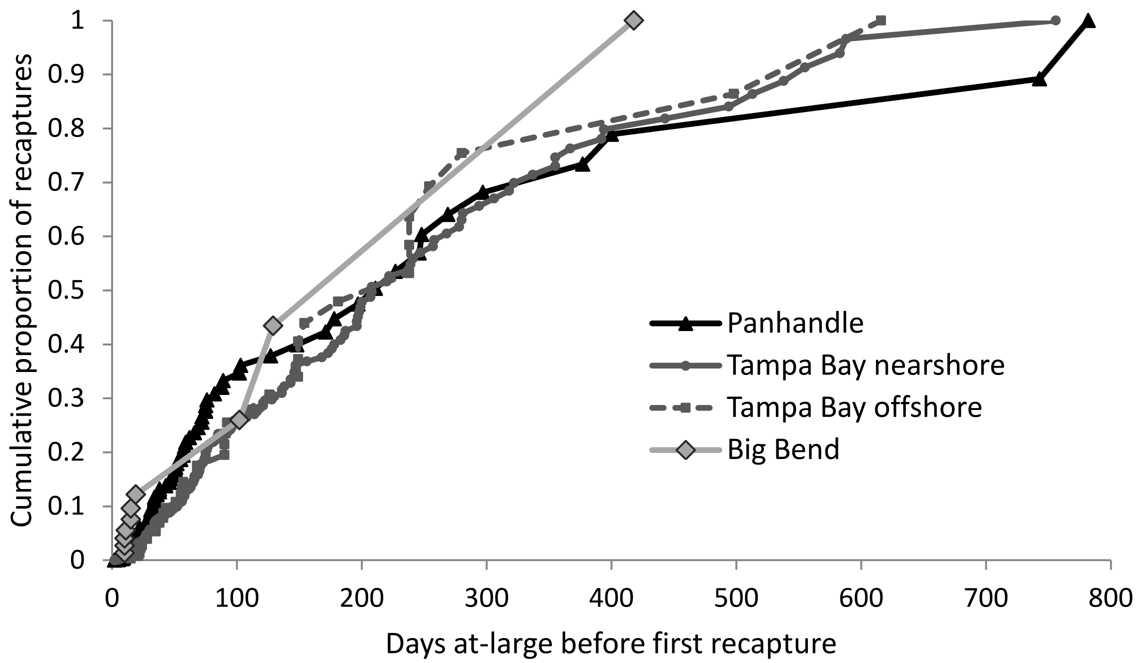

Figure 5. Days at-large before first recapture expressed as the cumulative proportion of total at-large times for all recaptured fish, by region. The median time at-large before first recapture was 34 days in the panhandle region, 55 days in the Tampa Bay nearshore region, 68 days in the Tampa Bay offshore 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 in the Big Bend region (n=10).

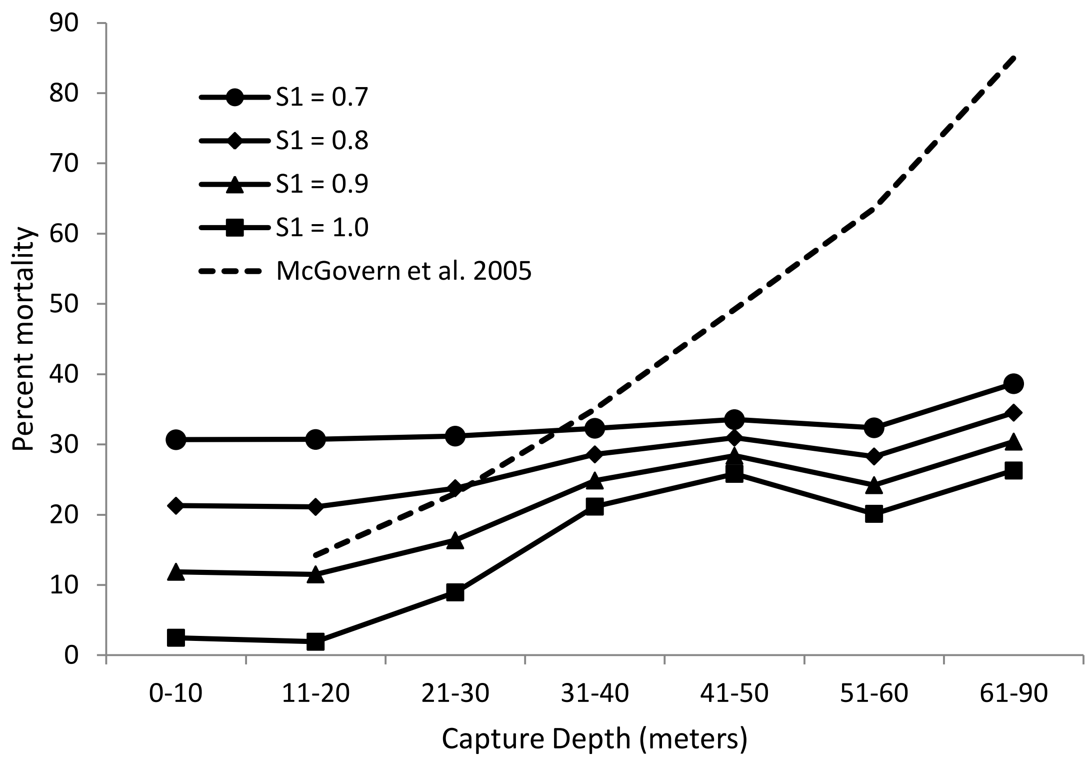

Figure 6. Overall estimated percent mortality for gags observed in 10 meter depth intervals, under variable assumptions for survival of gags released in condition category 1 (S1=1.0 to 0.7). Very few sampled trips in this study took place in depths >60 meters and gags captured in 61-90 meters are combined in a single depth interval (see Table 6 for sample sizes). Percent mortalities from McGovern et al. 2005 are also plotted for comparison.