Release Mortality Estimates for Recreational Hook-and-Line Caught Red Snapper Derived from a Large-Scale Tag-Recapture Study in the Eastern Gulf of Mexico

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Release Mortality Estimates for Recreational Hook-and-Line Caught Red Snapper Derived from a Large-Scale Tag-Recapture Study in the Eastern Gulf of Mexico.

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Introduction

Red snapper in the Gulf of Mexico are highly sought for their commercial and recreational value to the region and have experienced high degrees of fishing pressure. The first stock assessment for red snapper (*Lutjanus campechanus*) in the Gulf of Mexico indicated that the stock was undergoing overfishing as early as the late 1980's (Goodyear, 1988), and fisheries for this species have been increasingly regulated up to the present day as the stock continues to rebuild. In order to moderate the impacts from recreational fishing, a suite of regulations intended to reduce harvest have been implemented throughout the management history for red snapper. Regulations currently in place include minimum size limits, daily bag limits, and reduced harvest seasons. The unintended consequence is that more fish are released, and each release event has some probability of mortality. For fish that suffer from catastrophic decompression, serious hook injuries, or long handling times, the probability of mortality is potentially high (Rummer and Bennett, 2005; Rudershausen et. al, 2007; Burns et al., 2002; Wilson and Burns, 2004). Discard mortality can contribute significantly to total fishing mortality, and the ratio of discarded fish to landed fish can be quite high in recreational fisheries that tend to operate closer inshore where smaller fish reside.

Capture depth is and important factor that contributes to post-release mortality (Rummer, 2007). Other experimental studies have also identified factors in addition to capture depth that influence survival of released fish, and while their contributions to discard mortality are proportionately lower, these factors are potentially more important if capture depth exposure is low. Studies from shallow near-shore fisheries identify hook location as the most significant factor that determines discard survival (Murphy et al, 1995; Taylor et al, 2001). St. Johns and Sayers (2005) attributed 13.2% of release mortality of an Australian reef fish to hook injuries, which was in addition to depth-related mortality. Consequently, understanding where and how recreational fisheries operate is critical for assessing catch and release mortality. A few models have attempted to account for multiple and variable factors effecting discard mortality. Rummer (2007) used existing studies for red snapper as well as studies from surrogate species to develop a theoretical predictive model for estimating survival of red snapper released under variable conditions. The author reviewed over 200 catch and release studies for red snapper and up to 40 surrogate species to develop a model for predicting the response of red snapper to individual catch and release events. The model accounted for responses by different sized fish captured at different depths under variable retrieval conditions, handling exposures, and release conditions. Rummer acknowledged that ideally a study that collects a suite of data under multiple variable conditions should be used to assess the validity of the theoretical model approach developed for red snapper.

Use of a composite score to evaluate the combined effects of multiple stressors on predicted mortality was described by Davis (2010) and has been demonstrated as a viable method to evaluate the sub-lethal effects of catch-and-release fishing for red snapper (Campbell et al. 2009). A composite fish impairment score was used in the western Gulf of Mexico by Campbell et al. (2010) to relate immediate release mortality of red snapper to stressors induced by hook-and-line catch-and-release fishing. The composite score included a combination of barotrauma symptoms and reflex tests that were conducted while fish were out of the water and restrained. In the western Gulf study, there was a positive relationship between increased impairment score and capture depth and a significant seasonal effect, with greater impairment in summer months compared to fall months. The numbers of tagged and recaptured fish in the western Gulf study were too low to assess delayed release mortality.

Since June, 2009, the Fish and Wildlife Research Institute of the Florida Fish and Wildlife Conservation Commission has been conducting a large-scale, year-round tag-recapture study in the eastern Gulf of Mexico to assess the survival of reef fish released during recreational hook-and-line fishing. The study is ongoing and over 15,000 red snapper have been tagged and released to date. The objective of this analysis is to relate injuries and impairments measured during direct observations of red snapper caught and released within the recreational fishery to subsequent survival (calculated from tag-recapture rates), and assess the combined effects of depth and season on delayed mortality.

Methods

Observer Coverage:

Fishery observers were placed on participating charter and headboat vessels that operate on the west coast of Florida in the northwestern panhandle and central peninsula regions (Figure 1). Observers paid a passenger fare to board the vessel along with paying passengers and directly observe recreational fishing during the course of the trip. Each month, vessels were randomly selected for observer coverage from two regions (northwestern panhandle and central peninsula). Monthly sample quotas were assigned to three trip types: single day charter trips, single day headboat trips, and multi-day trips (only in central peninsula region). Fishery observers scheduled trips on randomly selected vessels each week of the month until sample quotas for each trip type were met.

In addition to randomly sampled recreational fishing trips, charter vessels were hired in the northwestern panhandle for directed red snapper research trips. The purpose of the directed trips was to catch red snapper using recreational fishing methods, and tag and release fish. During directed research 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 red snapper. All directed trips were conducted during the months of March through May.

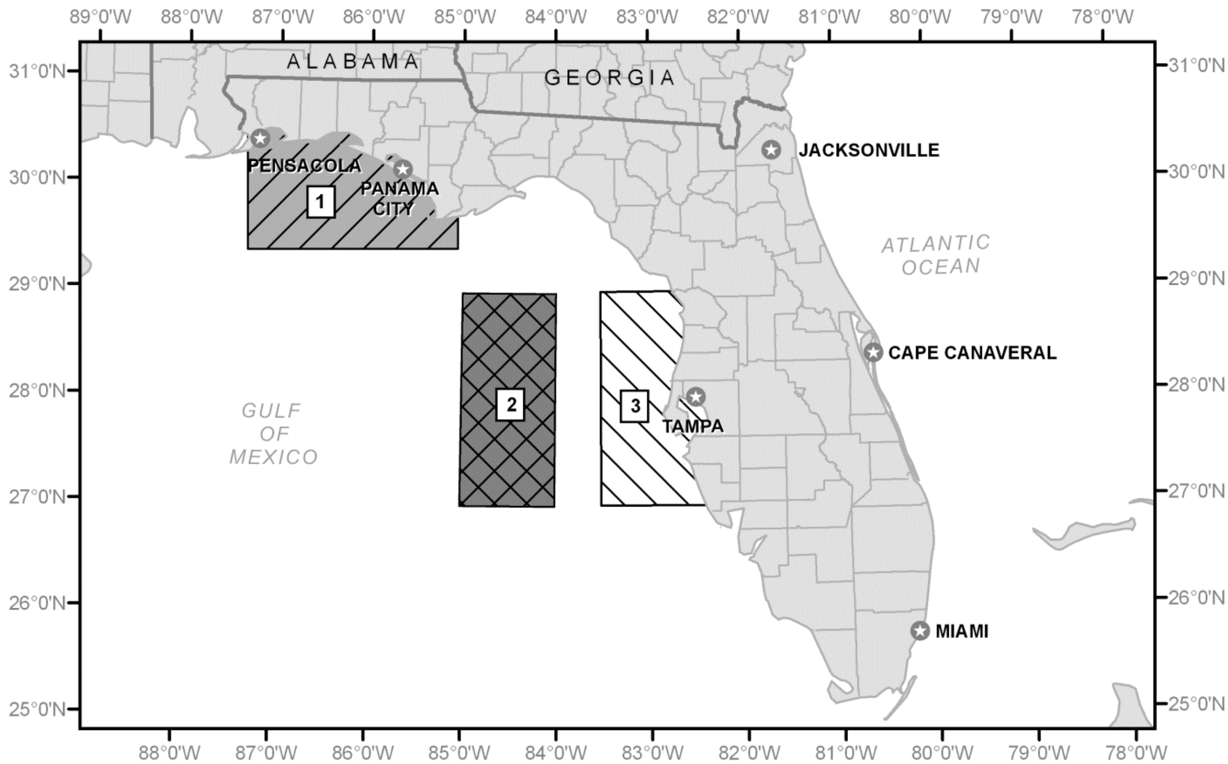

Figure 1. Study area. Box 1 is where trips from the northwestern panhandle region took place, box 2 is where multi-day trips from the western central region took place, and box 3 is where single-day trips from the western central region took place.

Field Procedures:

During a scheduled fishing trip, one to two fishery observers directly observed anglers during recreational hook-and-line fishing. During each sampled trip, depth and latitude/longitude (degrees and minutes) was recorded at each fishing station. For each red snapper caught and released, observers recorded information that included the size (mm fork length), location where the fish was hooked (lip, mouth, throat, gill, gut, eye, or external), the ease with which hooks were removed (easy, difficult, hook left in place), whether the fish was bleeding (indicating gill injuries), the presence or absence of barotrauma symptoms (swollen bladder, everted stomach, extruded intestines, and/or exopthalmia), whether the fish was vented or released without venting, and the release condition (good=swam below surface immediately; fair=disoriented, then swam below surface; poor=floating on surface and unable to submerge; dead=unresponsive and presumed dead upon release; preyed=visually preyed upon at the surface). Prior to release, 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".

Mark-Recaptures:

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 postcards 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, size, and approximate location. When a recaptured fish was encountered by observers during a sampled trip on a charter boat or headboat, the observer recorded all the data elements described above in the Field Procedures section.

Immediate Mortality:

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

Impairment Scoring:

Each fish included in this analysis was given a composite presence/absence impairment score based on multiple factors that were measured in the field. The first impairment factor was swimming impairment. A swimming impairment was present if fish were initially disoriented or floating on the surface upon release (swimming impairment score=1), and was absent if fish immediately oriented themselves and swam below the surface (swimming impairment score=0). The second measure of impairment was whether the fish was vented (vent score=1) or released without venting (vent score=0). Venting is believed to be beneficial for many fish because it enables fish exposed to varying degrees stress from barotrauma that may otherwise be left to perish on the surface to successfully re-submerge. However, venting also increases handling time, risk of injury due to improper methods, and some effects of severe barotrauma exposure may not be mitigated by venting. Thus, some impairment may not be accounted for based solely on observations of behavior at the surface, and it is likely that survival of vented fish is something less than 100% compared to fish that did not require venting and quickly re-submerged.

The third impairment factor was the presence or absence of exopthalmia, which is an indicator of severe barotrauma exposure (barotrauma score=1 for presence, 0 for absence). This particular symptom of barotruama is easily identified and presence/absence is clearly distinguished. Several other barotrauma symptoms measured in the field were evaluated, and the reasons for their exclusion from impairment scores is discussed in the results section. The fourth measure of impairment was the presence or absence of an internal hook injury, where the impairment was present if a fish was hooked in the throat, gill, gut, or through the eye (hook injury score = 1) or absent if a fish was hooked inside the mouth or lip or foul hooked externally (hook injury score=0). The fifth measure of impairment was the presence or absence of bleeding, which was observed whenever there was injury to the gills or bleeding from hook injuries.

The minimum impairment score an individual fish could receive was 0 (hooked in the lip or mouth, no bleeding from gills, released without venting, no exopthalmia, and swam down in good condition). The maximum impairment score was 5 (hooked internally, bleeding from gill or hook injuries, vented, exopthalmia, and released in fair or poor condition). Proportional impairment (PI) scores for groups of fish were calculated using the equation described by Davis (2010) as:

$$PI = \frac{\text{sum of individual impairment scores for all fish}}{\text{maximum possible score for all fish}}$$

PI scores were calculated for each of four seasons and four groups of fish: 1) legal size ($\geq$406mm TL) and caught in EEZ; 2) legal size and caught in STS; 3) sublegal size (<406mm TL) caught in the EEZ; and sublegal size caught in STS; where EEZ is the Exclusive Economic Zone and STS is state territorial seas. Seasons were defined as winter (January through March), spring (April through June), summer (July through September), and fall (October through December).

Relative Survival of Fish Exposed to Varied Numbers of Impairments:
In epidemiology studies, the risk ratio measures the probability of an outcome in subjects exposed to some risk for a particular outcome (such as death or disease) compared to subjects that were not exposed to the same risk. The use of a risk ratio to calculate relative survival (S) in fish tag-recapture studies was described by Hueter (et al., 2006) and calculated as:

$$S = Re/Ru$$

Where Re and Ru are the recapture rates for tagged fish that were either exposed (e) or unexposed (u) to some measured risk that reduces probabilities for survival. Recapture rates for each exposure group are calculated as the total number of fish tagged and subsequently recaptured, divided by the total number of fish tagged.

Because fish in this study were tagged year-round over the course of three years (June, 2009 through June, 2012), it was necessary to account for the varying amounts of time each fish was vulnerable to recapture. A simple method to account for time is to calculate tag recapture rates (RR) as a time-dependent rate for fish in each impairment score category (0 to 5 impairments present) using the formula:

$$RR = Rn / Tn$$

Where Rn is the total number of recapture events for fish with n impairments present, and Tn is the total number of days that all tagged fish with n impairments were at large before they were either recaptured or the end of the evaluation period was reached. Relative survival (RS) for impaired fish is then calculated relative to fish with 0 impairments, similar to the method described above, using a rate ratio:

$$RS = RRe/RRu$$

Where RRe is the recapture rate for fish exposed to e=1, 2, 3, 4, 5 or 6 impairments; and RRu is the recapture rate for fish that were exposed to u=0 impairments (unexposed). This is a slight modification of Hueter et al.'s method that takes into account varied amounts of time that individual fish were observed in this study. The rate ratio is approximate to relative risk when the risk of an outcome (in this case, recapture) over the period of observation is low in both the exposed and unexposed groups (Kelsey et al. 1986). Typically, recapture rates in fish tagging studies are less than 10%. Confidence intervals (CI) were constructed around the RS using:

$$95\%\ CI = \exp[\ln(RS) \pm 1.96 * \mathrm{sqrt}(1/a + 1/c)]$$

Where a is the number of recaptured fish in the exposed group and c is the number of recaptured fish in the unexposed group.

An important assumption noted by Heuter et al. that must be met when calculating relative survival from tag return rates is that all fish in the study have approximately equal catchabilities and equal probabilities for recapture. For this analysis, it was necessary to account for potential differences in recapture rates due to concentrated recreational fishing effort near shore in state territorial seas (STS), versus farther offshore in the Exclusive Economic Zone (EEZ). It was also necessary to account for potential differences in recapture rates for legal sized fish, which are more likely to be harvested and tag returns reported, versus sublegal sized fish that must be released and for which tags are more likely to go unnoticed. To account for spatial variability in recapture rates for tagged fish, recapture rates (RR) between exposed and unexposed groups were evaluated separately for legal and sublegal sized fish captured in STTS and the EEZ.

Another confounding factor that could affect tag recapture rates over the course of this study is the temporal variability in fishing effort within and among years. There was a noticable pulse in the frequency of tag returns reported to the FWC tag return hotline each year at the opening of the harvest season and for a short period of time following the closure, largely due to increased fishing effort targeting red snapper during the months that harvest was permitted. When this study began in 2009, the red snapper recreational harvest season was June 1 through August 14. The harvest season was shortened in 2010 to June 1 through July 24; however, a large portion of federal waters in the study area were closed to fishing in the summer of 2010 following the Deepwater Horizon event in the Gulf of Mexico. A supplemental weekends only harvest season was established in fall 2010 (Fri-Sun, Oct. 1 to Nov. 21), and shortened summer harvest seasons were resumed in 2011 (June 1 to July 18) and 2012 (June 1 to July 16). The effect of this temporal change in fishing effort on tag return rates (particularly when the rate is measured in units of time) is that fish tagged farther in advance of the season opening date are more likely to be at large for a longer period of time before recapture then fish tagged closer to the season opening date. Since a large proportion of red snapper in this study were tagged in the March, April and May just prior to the opening of summer harvest seasons, it was important to account for covariates, such as the time of year that a fish was tagged, on the probabilities of recapture for individual fish.

To test the significance of potential covariates and control for their effects on relative recapture rates, a separate analysis using the Cox Regression proportional hazard model (PHREG procedure in SAS) was employed. The proportional hazard model estimates the hazard (h) for an individual i to experience an event at time t as the product of:

$$h_i(t) = \lambda_0(t)\exp(\beta_1 x_{i1} + \ldots + \beta_k x_{ik})$$

Where $\lambda_0(t)$ is the baseline hazard function for an individual when all covariates equal 0; and the exponentiated term is a linear function of a set of k fixed covariates (Cox 1972; Allison 2010). 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. Thus, the hazard ratio is similar to the rate ratio with the added feature of controlling for covariates on one or both rates.

The hazard ratio for two treatment groups is interpreted similar to the odds ratio in logistic regression. In this analysis, the variable for n impairments was coded for with three dummy variables for n=1, n=2, and n=3 or greater impairments (since fish with 4 or more impairments were rare observations), and each combination of dummy variables was referenced against fish with 0 impairments (dummy variables all = 0) to get the estimated hazard ratio. Covariates tested for inclusion in the model included the number of days before the first day of an open harvest season, which was calculated as the season open date for the year of original capture minus the date of original capture. To account for the oil spill area closure, if a fish was originally captured prior to October 2010 in the EEZ, the opening of the fall supplemental season was used, and either the summer or fall season opening date was used for fish originally captured in STTS, depending on the time of capture. Other covariates tested for significance included class (dummy) variables for season (winter, spring, summer, fall) and region of capture (EEZ, STTS); continuous variables for capture depth (meters) and size at original capture (mm total length); and possible interaction terms. Since the effect of year of entry into the study was not of direct interest for this analysis, the model was stratified by year to control for changes in fishing effort across years of the study. An assumption of this model was that the effects of loss to the study due to tag shedding, tag fouling, non-reporting, and other mortalities affect all fish tagged in a given entry period into the study in the same way, regardless of their physical condition upon release. For example, when the effects of covariates on recapture rate are accounted for, a fish released with three or more impairments in 2009 is assumed to have the same probability for recapture after x days at large as another fish released in 2011 in the same condition and the same days at large.

Predicted Survival of Tagged Fish Population:
For each season (pooled for all years of the study), the number of fish that were tagged and released in each size category (legal and sublegal) and region (STTS and EEZ) were summed for each impairment category (0, 1, 2, etc. impairments). Each sum was multiplied times the relative survival (S) for a given group, and separately by the rate ratio or hazard ratio, to get numbers of tagged fish in each season that were estimated to have survived using each method. The number of tagged fish estimated to survive in a given group was then divided by the total number of fish tagged in that group to get the proportional survival. Proportional mortality was simply M=1-proportional survival. Proportional impairment (PI) scores for each fish group were plotted against proportional mortality (M), and linear regression coefficients for the two methods were compared (using PROC REG in SAS). The null hypothesis tested was Ho: $\beta r = \beta h$, where βr is the regression coefficient for proportional mortality calculated from relative risks, and βh is the regression coefficient for proportional mortality calculated from hazard ratios.

Data Reductions
Red snapper tagged from Area 1 in Figure 1 were only considered for this analysis. Since this study is ongoing, tag returns from other regions of the study are still low.

Results

Over 15,000 red snapper were tagged and released year-round from 428 separate trips over the course of three years, between June 2009 and June 2012 (Table 1). The mean capture depth for red snapper that were tagged and released in this study was 31 meters (range 8 to 106 meters). The distribution of capture depths is presented in Figure 2, and summary statistics for depth and size at time of capture are provided in Table 2. Immediate mortalities in this study were low and represented less than two percent of red snapper that were not harvested (Table 3).

Table 1. Number of trips and numbers of red snapper tagged and released.

	NW Panhandle		**Central Peninsula**		**Big Bend**	
	Trips	Fish	Trips	Fish	Trips	Fish
Recreational charter trips	167	2,922	14	58		
Recreational headboat trips	116	1,445	19	95		
Recreational multi-day trips			32	815		
Directed research trips	75	9,398			5	404

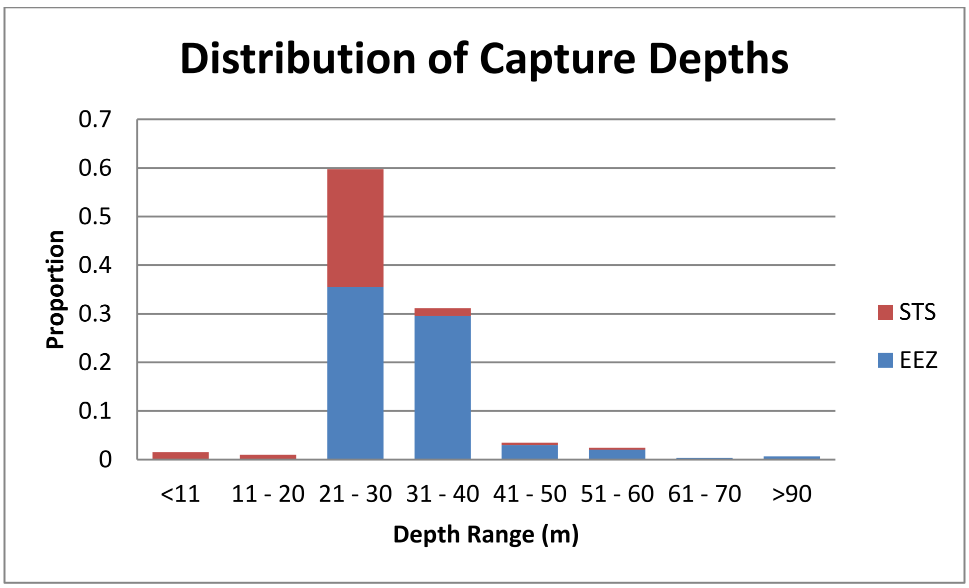

Figure 2. Distribution of capture depths (in meters) for all red snapper tagged in this study. Brown represents the proportion of all tagged fish that were captured in state territorial seas (STTS) within 10 statute miles from shore, and blue represents the proportion captured in the Exclusive Economic Zone (EEZ) >10 statute miles from shore.

Table 2. Mean depth of capture and size for legal and sublegal sized red snapper.

	Depth (m)		Legal Size (mm TL)		Sublegal Size (mm TL)	
	Mean	Range	Mean	Range	Mean	Range
EEZ	32	23-106	503	406-1034	367	373-405
STS	26	8-60	497	406-833	365	153-405

Unpublished thesis research, not for distribution.

Table 3. Numbers of non-harvested fish and percent immediate mortalities observed.

	Legal Size		Sublegal Size	
	Number Observed	Immediate Mortalities	Number Observed	Immediate Mortalities
≤30m depth	4,857	0.80%	2,258	1.15%
>30m depth	6,673	0.36%	2,723	1.29%

Impairment Scores

Composite impairment scores for individual fish was the sum of presence/absence scores for swimming impairment, venting, barotrauma, internal hook injury, and bleeding from gills or other injuries. The presence or absence of exopthalmia was the sole indicator for barotrauma. Unlike other symptoms, exopthalmia is readily recognized in the field the condition and present only when barotrauma is severe. The condition was rare compared to other symptoms (Table 3). More than 95% of tagged fish exhibited at least mild exposure to barotrauma at the time of capture. The presence of a swollen bladder was the most prevalent barotrauma symptom (Table 3). When this symptom was included in impairment scores, very few fish were left in the exposure category for 0 impairments, and relative survival of fish with one impairment was close to 100% or greater when compared to fish with 0 impairments. Therefore, this symptom could not be considered an impairment to survival and was not included in the composite scores. The presence or absence of an everted stomach and extruded intestines were also unreliable predictors of impairment. For both measures, presence sometimes (but not consistently) was recorded for mild symptoms as well as more severe symptoms. Some observers recorded the presence of an everted stomach if they could see eversion in the esophagus, while other observers only recorded presence if the stomach was visible inside or beyond the buccal cavity. Some observers also recorded the presence of intestinal extrusion if there was swelling in the area around the opening of the anus. Impairment scoring methods described by Davis (2010) stressed that for impairment scores to be useful, scores should be consistent and mild symptoms should be coded as absent whenever there is doubt about the presence or absence.

Table 3. Percent of released fish with observed barotraumas.

Capture Area	**Size Class**	**Swollen Bladder**	**Extruded Intestines**	**Exopthalmia**	**Everted Stomach**
EEZ	Legal	98.0%	42.7%	0.23%	39.9%
	Sublegal	96.9%	36.1%	1.09%	35.9%
STS	Legal	99.4%	44.9%	0.05%	23.8%
	Sublegal	94.1%	35.0%	0.79%	27.9%

Proportional impairment was calculated separately for legal and sublegal size classes of fish caught in the EEZ and in STS and are plotted in Figure 3. Proportional impairment peaked during summer months for legal and sublegal sized fish captured in the EEZ, and was more variable across seasons for legal and sublegal sized fish captured in STS (Figure 3).

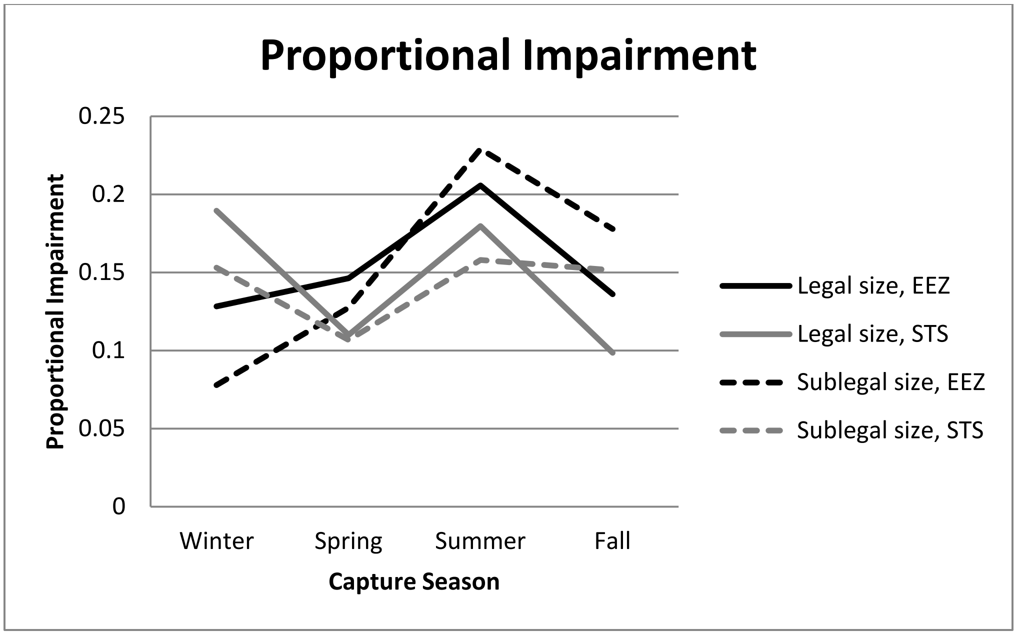

Figure 3. Impairment, expressed as a proportion, for legal and sublegal sized red snapper caught in shallow and deep depths by season of original capture.

Relative Survival Using the Rate Ratio:
Relative survival of tagged fish using the rate ratio, calculated from tag recapture rates for fish with n impairments relative to fish with 0 impairments, decreased significantly with increasing n for legal sized fish. Relative survival for sublegal sized fish also decreased with increasing number of impairments; however, confidence intervals include 1.00, indicating that relative survivals compared to fish with 0 impairments were not significant (Table 4). Tag recapture rates for sublegal sized fish were low overall, and very few sublegal fish with more than 2 impairments were observed. Frequencies for fish with n impairments were calculated for four groups of fish: 1) legal size and caught in EEZ; 2) legal size and caught in STS; 3) sublegal size caught in the EEZ; and sublegal size caught in STS (Table 4). The estimated number of tagged fish that survived in each category is the product of the frequency of tagged fish times S in Table 4, and the proportional survival is the total number of estimated survivors in each group, divided by the total number of fish tagged in each group. Proportional impairment and proportional mortality (M = 1-proportional S) were also calculated individually for each group in Table 4 by capture season (winter, spring, summer and fall), and results are plotted in Figure 4. Over all points, there was a positive linear relationship between proportional impairment and mortality. Proportional mortality increased linearly with increasing impairment (intercept=0.036, slope=1.20, p =0.001, r-square=0.54) and was noticeably higher for fish caught in STS compared to fish caught in the EEZ, especially for sublegal sized fish in the EEZ (Figure 4).

Table 4: Numbers of fish tagged and recaptured by size class and area of capture across all years and seasons; relative survival (S) and 95% confidence intervals calculated from rate ratios for fish with n=1,2,3 and 4 impairments relative to fish with 0 impairments; estimated number of survivors (number tagged*RS); and proportional survival = (sum survivors/sum tagged).

	n	Number Tagged	Number Recaps	S	RS 95% CI	Estimated Number of Survivors	Proportional S
Legal size caught in EEZ	0	1,653	253	1.0		1,653	
	1	2,731	293	0.73	0.62-0.87	1,994	
	2	280	16	0.34	0.20-0.56	95	
	3	52	2	0.24	0.06-0.95	12	
	4	3	0	0		0	
	Sum	4,719	564			3,754	0.796
Sublegal size caught in EEZ	0	814	42	1.0		814	
	1	1,185	49	0.82	0.54-1.24	972	
	2	167	5	0.52	0.21-1.32	87	
	3	24	0	0		0	
	4	0					
	Sum	2,190	96			1,873	0.855
Legal size caught in STS	0	878	156	1.0		878	
	1	986	116	0.67	0.53-0.85	661	
	2	70	5	0.34	0.14-0.82	24	
	3	10	0	0		0	
	4	2	0	0		0	
	Sum	1,946	277			1,563	0.803
Sublegal size caught in STS	0	351	21	1.0		351	
	1	485	19	0.67	0.36-1.25	325	
	2	44	0	0		0	
	3	4	0	0		0	
	4	0					
	Sum	884	40			676	0.765

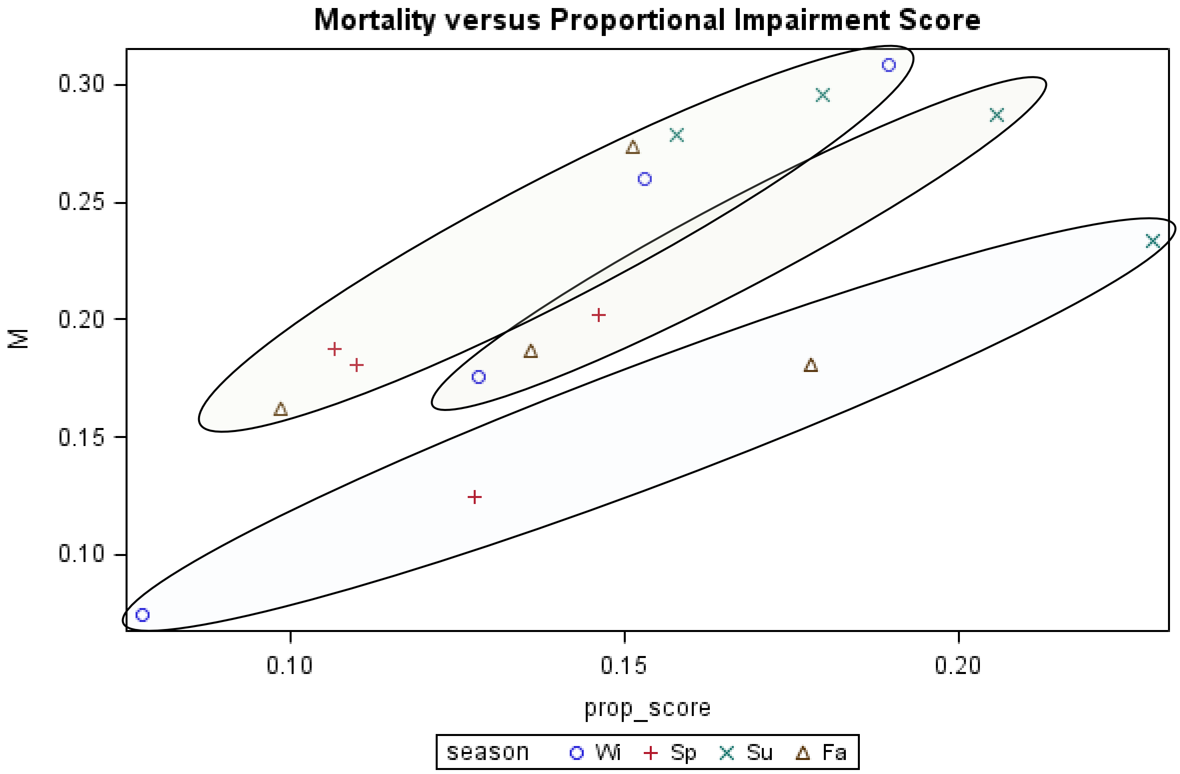

Figure 4. Proportional impairment (x axis) plotted against proportional mortality (y axis) using the rate ratio for sublegal and legal sized fish in the EEZ and STS for each capture season (see legend). The upper ellipse includes points for legal and sublegal sized fish captured in STS; the middle ellipse includes points for legal sized fish caught in the EEZ, and the lower ellipse includes points for sublegal sized fish caught in the EEZ.

Proportional Hazard Model:
In the proportional hazard model, the instantaneous rate or *hazard* of recapture was modeled against explanatory variables for fish with n=1, 2, and 3 to 4 impairments (coded as dummy variables). Hazard ratios for each n were referenced against fish with 0 impairments. Controlling for all significant covariates, the hazard ratios decreased significantly for fish with increasing numbers of impairments (Table 5; alpha=0.05). The hazard for recapture for fish with n=1 impairment was 67.4% of the hazard for fish with 0 impairments, and decreased to 34.6% for fish with n=2 impairments and 17.6% for fish with n=3 or more impairments (Table 5). Proportional impairment scores are plotted in Figure 5 against proportional mortalities for each group and season (intercept=0.003, slope=1.60, $p < 0.0001$, r2=0.9994). The r2 improved because the proportional hazard model produces one hazard ratio for fish of all sizes and capture depths in a given impairment category. When regression coefficients for points in Figures 4 and 5 were compared, there was no significant difference between slopes (T = -1.35, p = 0.19).

Several covariates were tested for significance and inclusion in the proportional hazard model using forward stepwise selection procedures. Fish length (mm TL) and capture depth (m) were significant and included in the final model (Table 5). For each one meter increase in depth of capture, the hazard for recapture decreased by an estimated 1.8% (percent reduction calculated as 100*(hazard ratio-1)). Comparing the bottom panels from Figure 4 and Figure 5, there is an apparent increase in estimated proportional mortalities in the EEZ, while proportional mortalities in STS remain unchanged between the two methods. Depth was not directly accounted for in rate ratios, and relative survivals were calculated separately for fish caught from the EEZ and STS. However, depth of capture may do a better job of accounting for changes in fishing effort with increasing distance from shore. Area of capture (EEZ, STS) was not a significant covariate in the proportional hazard model and was not included.

The effect of size at original capture had the opposite effect of depth of capture. For every 1cm increase in size at time of capture, the hazard for recapture increased by 4.1%. Some harvesters reported to us that they did not notice tags until fish were being cleaned. Since smaller fish are more likely to be released, possibly before tags are noticed, recaptures for smaller fish may go unreported more often. If the increasing hazard for recapture with size was indicative of increased survival, this effect would also be measured in impairment scores; thus, including size as a covariate removes any potential confounding effects from differences in tag reporting rates for larger fish without influencing hazard ratios for fish with one or more impairments. The interaction between size and depth of capture was not significant.

The covariate for season of original capture and release was coded for with three dummy variables for winter (Jan-Mar), spring (Apr-Jun) and fall (Oct-Dec), and all three variables were referenced to summer (Jul-Sep). The hazard for recapture for fish originally tagged and released in the fall was 2.15 times greater compared to fish released in the summer, and the hazard for fish released in spring and winter was 2.69 and 2.75 times greater, respectively (Table 5). Interaction terms for season*depth and season*area (EEZ, STS) were not significant. The covariate for number of days released prior to the harvest season opening was also significant; however, this effect was also accounted for with season of original capture. Season was retained in the final model and days before harvest season was dropped.

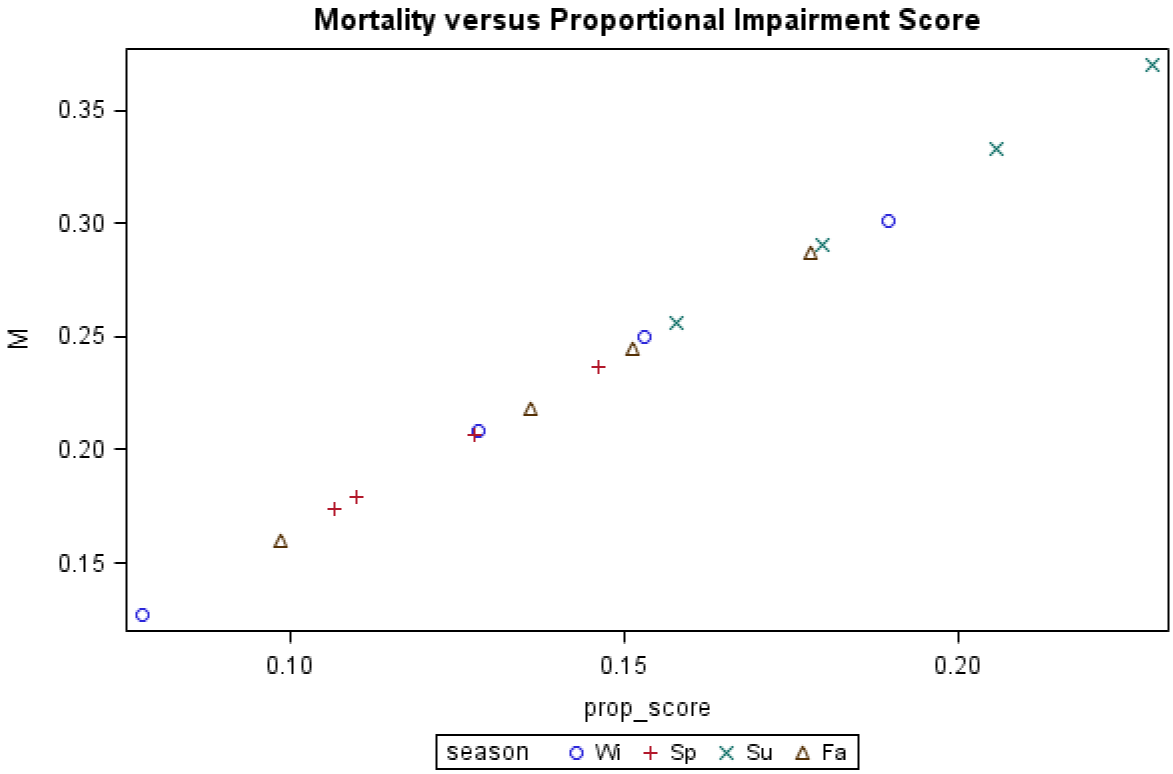

Figure 5. Proportional impairment (x axis) plotted against proportional mortality (y axis) using the hazard ratio. Points for each capture season (top) and region (bottom) are coded for by the legends.

Unpublished thesis research, not for distribution.

Table 5. Analysis of maximum likelihood estimates from SAS output for all variables included in the proportional hazard model. Dummy variables for red snapper with n=1, 2, 3-4 impairments were included in the PHREG model statement and compared against the reference variable for fish with 0 impairments. Covariates included in the model were number of days each fish was at large prior to the opening of the first harvest season, length at time of capture, depth of capture, and year of capture (two classes referenced against 2009).

Parameter	D.F.	Parameter Estimate	Standard Error	Chi Sq	Pr>Chi Sq	Hazard Ratio
1 Impairment	1	-0.395	0.0679	33.87	<0.0001	0.674
2 Impairments	1	-1.061	0.2067	26.35	<0.0001	0.346
3-4 Impairments	1	-1.740	0.7093	6.02	0.0142	0.176
Length	1	0.004	0.0003	158.82	<0.0001	1.004
Depth	1	-0.020	0.0046	19.11	<0.0001	0.980
Fall vs. Summer	1	0.767	0.2227	11.85	0.0006	2.152
Spring vs. Summer	1	0.988	0.2049	23.26	<0.0001	2.686
Winter vs. Summer	1	1.011	0.2170	21.71	<0.0001	2.748

Discussion

The concept of relative survival assumes that all fish in the unexposed treatment group survive catch and release. However, if some portion of fish in the unexposed group actually do not survive, then mortality is underestimated. Therefore, it is desirable to exclude as many fish as possible from the unexposed group if they have a reduced chance for survival. Use of the composite impairment score is useful for this purpose because it allows fish to be excluded from the unexposed treatment group, even when they suffer from impairments that are rare among all observations and cannot be assessed individually. Other survival studies have used release condition at the surface as the single distinguishing factor (Hueter et al 2006); however, this underestimates mortality if fish with acute injuries are able to swim away in good condition and are included in the unexposed treatment group. Release condition at the surface is also directly influenced by venting, and studies that only consider release condition do not distinguish between vented and unvented fish. The benefits of venting are not clear and may increase injury, particularly if fish are improperly vented (Wilde, 2009). Furthermore, internal injuries suffered from rapid ascent at deeper depths cannot be mitigated by venting (Rummer and Bennett, 2005). Comparing relative survival of fish in an unexposed group to an exposed group is useful for accounting for partial survival, and studies that assume fish with certain impairments suffer 100% mortality may overestimate mortality. For example, a survival model for reef fish discards in a commercial hook and line fishery off North Carolina assumed all fish with gastric distension did not survive after release (Rudershausen et al 2007); however, work by Burns (2009) indicates that this symptom is not lethal at all depths, and some portion of fish captured at deeper depths are capable of recovering from this condition.

Immediate mortality in this study was very low compared to studies in Texas (Dorf 2003, Diamond and Campbell 2009, Campbell et al 2010) and comparable to Alabama where 86% of red snapper submerged immediately (Patterson et al. 2001). Predation at the surface was included in immediate mortality; however, one potential factor that could not be accounted for in this study is mortality associated with removal of fish from the protective cover of the reef, and subsequent release at the surface. Any predation beneath the surface as fish swam through the water column could not be observed. If impaired fish were preyed on more heavily than unimpaired fish, it would be accounted for in comparisons of tag return rates between treatment groups. However, an assumption of proportional survival is that the reference group represents 100% survival, which may not be true if they, too, are subject to predation. Sub-surface predation is an aspect of catch-and-release mortality that needs future study.

The relative risk method described by Hueter et al (2006) is sufficient for tag-recapture studies where fishing effort is constant across spatial and temporal scales. The rate ratio method described here, which was a slight modification of relative risk, did a good job of estimating proportional mortality for red snapper in STS since proportional mortality remained unchanged after covariates were controlled for in the proportional hazard model. However, proportional mortality was underestimated for red snapper caught in the EEZ using the rate ratio method, particularly for sublegal sized fish. By incorporating covariate effects on tag return rates, including depth of capture, fish size, and season of capture, proportional impairment was a better predictor of mortality for sublegal and legal sized fish in the EEZ. Conditions where the assumptions of equal catchabilities and/or equal probabilities for recapture holds true for all fish are unlikely in large-scale studies such as this one, and effects of covariates on tag recapture rates must be controlled if relative survival estimates are to be meaningful. Episodic events in open marine environments, such as oil spills and tropical storms, and numerous other factors, including the cost of fuel, shifts in the economy, and annual weather patterns all affect marine recreational fishing effort on spatial and temporal scales. For red snapper and many other fisheries in the Gulf of Mexico and the South Atlantic, fishing effort has become increasingly influenced by management that is dynamic and responsive to the fishery. The result for the red snapper recreational fishery in the Gulf of Mexico has been a contracted seasonal concentration of directed fishing effort, and longer durations during which fish are vulnerable only to indirect effort. The differential response between the EEZ and STS after the effect of covariates on recapture rates over time was removed is evidence that management also influences the spatial distribution of fishing effort. Proportional mortality in STS did not change when covariates were factored in, indicating that fish in this area are subject to more stable levels of effort. Fish in the EEZ are likely more impacted by seasonal pulses in directed fishing effort during open harvest seasons compared to STS. Differences in reporting rates for harvestable and sublegal sized fish were also evident from this study, and the effect of heterogeneity in capture rates on survival estimates has been shown by Pledger et al (2003).

This analysis unveiled a potential seasonal effect on release survival for red snapper. The covariate for season was significant for fish caught and released in winter, spring, and fall when referenced to summer (July-Sep). The summer time period began in July, which was near the end of recreational harvest seasons each year (except fall 2010 when the season was briefly reopened). Thus, fish released in the latter half of the summer period were at large for the longest number of days prior to the opening of the following year’s summer harvest season, which was the purpose for including season as a covariate in the model. However, red snapper caught during summer also had the highest proportional impairment scores, particularly for fish caught in the EEZ. After the covariate effect of capture season was controlled for in the proportional hazard model, proportional mortalities for legal and sublegal sized fish caught in the EEZ had the highest estimated mortalities of any group. This result is supported by previous findings in Texas where impairment scores for red snapper caught with hook-and-line gear were significantly higher in summer versus fall (Campbell et al 2010). The Texas study also found a significant interaction between season and depth treatments (30m and 60m). There was not a significant interaction between depth and season in the proportional hazard model; however, the mean depth for this study was 26m-32m (STS and EEZ respectively) and very few observations were from depths 60m or greater. Ideally, water temperature is a more direct variable to test for interaction with depth. Unfortunately, surface and bottom water temperatures were not collected as this study was designed to be as un-intrusive as possible to patrons of cooperating fishing vessels. The advantage of an observational study is that conditions experienced within the fishery are directly measured, and the variables and covariates collected during this study that were included in the final model can be rapidly collected in the field without interruption to the fishery under observation.

The proportional hazard model has been widely used as a tool in the study of human populations (Allison 2010), and is a promising tool for complex tag-recapture studies where it is desirable to compare treatment groups and control for covariates. The method requires no input or assumptions on the shape of the distribution of survival times. Non-recaptured fish are treated as time-censored observations, and easily handles variable observation times. Stratification of observations across long study periods was also possible, owing to the large sample sizes in this study.

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