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Release mortality in the red snapper fishery: a meta-analysis of three decades of research

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Abstract

Catch-and-release fishing (CAR) has been successfully practiced to promote sustainable fisheries and is widely accepted by many anglers as a wise conservation strategy. The value of CAR strategies as a conservation measure is highly dependent upon the release mortality rate and stock assessments depend upon accurate estimates of this rate. Differences in release mortality estimates from different studies complicate decisions about what values to use in fishery stock assessments. This analysis uses a random-effects meta-analytic approach to integrate results from 12 studies conducted over thirty years to model release mortality as a function of various covariates while accounting for differences in experimental protocols. Release mortality estimates varied due to depth of capture, venting protocol, experimental method season in which fish were released and whether the fish were captured by commercial or recreational fishing methods. High unexplained variability indicates there are likely other influential variables affecting release mortality that were not measured in the set of studies analyzed. Estimates derived from this study provide a critical input for the Gulf of Mexico red snapper stock assessment.

Introduction

The use of catch and release (CAR) fishing as a conservation measure began in Great Britain during the 19th century, and was eventually practiced in the United States voluntarily by the turn of the century and in the 1950's first used as a management tool in salmonid fisheries (Policansky 2002). Since that time it has been successfully practiced to promote sustainable fisheries and is widely accepted by many anglers as a wise conservation strategy. The intent behind CAR regulations is to reduce fishing mortality for important age groups of fish, often to allow young ages to grow and mature to reproductive ages or to protect spawning adults. Catch-and-release requirements have expanded in recent years to encompass the release of all size classes during seasonal (or longer) closures in response to the federal Fisheries Management Conservation Act that places strict limits on total removals, including open-access recreational fisheries. Despite the intent of CAR fishing regulations, for many species, capture stress can lead to increased frequency of barotrauma injuries and reduced reflex responses resulting in increased release mortality and rendering catch and release measures ineffective (Davis 2010, Campbell et al. 2010a). Stressors experienced by fishes during CAR fishing can include hooking trauma, physical overexertion, barotraumas, rapid thermal change, air exposure, and physical handling (Davis et al. 2001, Rummer and Bennett 2005, Nieland et al. 2007, Jarvis and Lowe 2008). These CAR fishing stressors may also translate into long-term, sub-lethal, negative consequences such as reduced growth and fecundity (Woodley and Peterson 2003, Ryer et al. 2004, Davis 2007). The effects of CAR fishing can be particularly problematic for marine species such as red snapper (*Lutjanus campechanus*) that inhabit relatively deep water and possess a physoclistous gas bladder.

Red snapper have been fished in the Gulf of Mexico (GOM) for over a century and are the most economically important fishery in the region (Strelcheck and Hood 2007). The first regulations managing the fishery were put in place in 1984 in response to the overfished status of the stock (see Hood et al. 2007 for a comprehensive management history). In general management has focused on annual time closures and minimum size regulations which increased the number regulatory discards, particularly in open-access recreational fisheries. Management of commercial fisheries has recently shifted to an annual catch share system, which removed the necessity to discard fish during seasonal closures, but still does not eliminate regulatory discards if fishers target other reef associated species after annual catch shares are exhausted.

Management focus has also shifted to regulations intended to reduce or minimize discard mortality. In 2008, regulations were adopted in the Gulf of Mexico requiring commercial and recreational fishers to use circle hooks and to use a venting tool when catching reef fishes. Venting tools are used to puncture and deflate the swim bladder after fish are rapidly retrieved as a means to mitigate the effects of decompression (barotrauma). Recent research indicates that circle hooks are beneficial for reducing potentially fatal hook injuries for reef fishes caught with hook-and-line gear, particularly for red snapper (Sauls and Ayala, 2012). Whether venting reduces discard mortality is less conclusive (Wilde, 2009). Results of studies to investigate the effects of venting particularly for red snapper that were evaluated by Wilde (2009) were mixed, with one that showed positive effects of venting on survival (Gitschlag and Renaud 1994), two that were neutral (Render and Wilson 1994, Render and Wilson 1996), and one that was negative (Burns 2004).

Regulatory discards account for an increasing portion of total catch for managed reef fishes and is often larger than the harvested portion both in number and weight. Quantifying the rate at which fish are discarded and their fate following release is a crucial data need for regional stock assessments in the Gulf of Mexico and South Atlantic. Due to the wide range in reported mortality rates (SEDAR 7 2005, Campbell et al. 2012) and the confounding nature of the potential interacting factors, a comprehensive evaluation of pertinent research is needed. Methods used to derive mortality estimates each have their benefits, biases and shortcomings that require exploration; however, in general, the problems are associated with the timing of observation, exclusion of predation, insufficient tag returns, sample size issues, artifacts of experimental protocols, and insufficient reporting of details (Campbell 2010a). Methods used to derive estimates include surface release observation, cage studies, hyperbaric chamber simulations, acoustic tagging, and passive tagging (Table 1). Mortality estimates from these studies are broadly categorized as either immediate (seconds to minutes), or delayed (hours to days). These different types of experiments, and therefore estimates, are often treated as equivalents when used in an assessment. While this aggregate approach is pragmatic it may result in the use of imprecise estimates and introduce unexplored or unknown sources of bias.

We present a meta-analysis approach with the intent of identifying critical issues and deriving a model of release mortality in the Gulf of Mexico red snapper fishery as a function of important covariates such as depth, season and capture gear. Meta-analytical methods allow inclusion of all available point estimates, includes a sample size weighting scheme, and allows for the use of covariates in a mixed-effects modeling approach (Viechtbauer 2010). The meta-analysis approach was developed, and is useful, because it reduces the introduction of bias that hinders non-parametric approaches often found in review papers (Sterne et al. 2000, Nakagawa and Santos 2012).

Methods

Data used in this meta-analysis were compiled from 12 studies that produced 75 distinct release mortality estimates (Table 1). There are multiple estimates from some studies because they were conducted at multiple water depths and/or seasons. Most of the estimates were compiled from refereed publications (Dorf 2003, Patterson et al. 2001, Render and Wilson 1994, Gitschlag and Renaud 1994, Nieland et al. 2007, Diamond and Campbell 2009, Campbell et al. 2010a); however, one was calculated from a publication that did not report a rate but did collect appropriate data (Patterson personal communication, *from* Addis et al. 2008) and several were only available from 'gray-literature' documents (Parker 1985, Burns et al. 2004, Diamond et al. 2011, Sauls 2012). Data were extracted from each publication relating to proportional mortality, water depth (m), study type (surface release, cage, passive tagging, acoustic tagging, and hyperbaric chamber), type of estimate derived (immediate or delayed), fishing sector evaluated (commercial or recreational), season (winter, spring, summer, fall, annual), hook type used in the study (circle or j hook), degree of venting (no venting, intermittent venting, or 100% venting), and sample size (n).

Several discrepancies about release mortality rates reported in the literature were found. The 10, 15, 20, and 25 m groups from Dorf (2003) appeared to be aggregated and reported as a single estimate for a 21-25 m depth group in SEDAR 7 (2005). The 30, 40, and 50 m values from Diamond and Campbell (2009) were aggregated and reported as annual estimates in SEDAR 7 (2005). Because there is uncertainty about why data were aggregated in the SEDAR 7 assessment workshop, this current analysis relied on published values as being representative of those works. Estimates originally reported in Nieland et al. (2007) reported individual fishing trip release mortality estimates. Many of those trips evaluated small sample sizes (*n* ~5 to 10) therefore mortality rates were re-calculated for discrete depth groups from the original data by aggregating trips by depth. Finally, the intent of the current study was to evaluate release mortality under fishing conditions, therefore, the Burns et al. (2004) estimates obtained from a hyperbaric chamber study were not included in the analyses.

The meta-analytical model used is a special case of a weighted general linear model as detailed in the metafor R package (Viechtbauer 2010). The analysis was performed on effect size (*es*) rather than raw proportions, where *es* is the logit-transformed proportion and was calculated as:

$$es = \log \left(\frac{x_i}{(n_i - x_i)}\right)$$

where x_i is the total number of individuals experiencing mortality and n_i is the total sample size. The estimate and the corresponding sampling variance were calculated using the escalc function in metafor (Viechtbauer 2010).

We fit *es* estimates in a mixed-effects model to evaluate the effects of depth, estimate type, fishing sector, season, hook, and venting compliance (Viechtbauer 2010). For the categorical variables the absence of group membership (i.e. setting the value to 0) by default defines the opposite group, and therefore there is no need to have all variables included. For instance, the only estimate type included in the model was delayed, and therefore any values set equal to 0 for the 'delayed' variable indicate values associated with immediate estimates. The dummy-coded fishing sector variable was commercial (0 = recreational). Dummy-coded seasonal variables included in the model were winter, spring, fall, and annual (0 = summer). The dummy coded hook variables included in the model were circle, and mixed (0 = J hook).

Dummy coded venting compliance variables included in the model were venting (100% venting), and intermittent venting (0 = no venting). The full estimated model is shown, below:

Prob(mortality) ~ depth + sector + measure + experimental treatment + season + hook type + study

Where depth of capture in meters is modeled as a continuous variable and all other variables are modeled as categorical. Sector is commercial or recreational, measure is immediate or delayed mortality, treatment is no vent, vented, intermittent venting, season is spring, summer, fall or winter, hook type is J, circle or mixed and study is modeled as a random effect. Study represents each individual study, or when a study was conducted over different seasons or with different treatments, individual studies were separated and each modeled as random effects. After removing non-significant factors and factor levels the model was re-estimated with only significant factors.

Heterogeneity (τ^2) was estimated using restricted maximum-likelihood (REML) then coefficients for μ, $\beta_0,\ldots,\beta_{p'}$ were estimated using weighted least squares in which each *es* estimate is weighted by the inverse of its variance. Wald-type tests and confidence intervals were calculated for μ, $\beta_0,\ldots,\beta_{p'}$ assuming normality. Based on the fitted model we calculated predicted values, and residuals. Cochran's *Q*-test was used to assess the amount of heterogeneity among studies (i.e. a null hypothesis of $\tau^2 = 0$). Predicted values and associated upper and lower bounds were then converted back to proportions by taking the inverse of the logit transformed effect size data as:

$$Proportion = \frac{exp^{es}}{(1 + exp^{es})}$$

Average model predictions were evaluated by giving equal weighting to the coefficients within fishing sector, venting, season and hook type and inputting a depth range of 10 to 200 m. Venting model predictions were evaluated by toggling the venting effect on. Seasonal model predictions were evaluated by toggling each season variable individually. All other coefficients for the venting and seasonal predictions were set to the intercept and both effects were evaluated for each fishing sector separately.

Results

Release mortality estimates ranged from 0 – 91% over the spectrum of studies evaluated (Table 1, Figures 1 and 2). The lowest estimate was 0% and was associated with a hyperbaric chamber study (Burns et al. 2004), and the highest 91% which was associated with the only data available from the commercial fishing sector (Nieland et al. 2007). Surface release estimates were the most common, followed by passive tagging, cage, hyperbaric chamber, and acoustic tagging (Table 1, Figure 1). Summer release estimates were the most common, followed by winter, fall, spring, annual, and unknown (Table 1, Figure 2). Studies were primarily conducted from depths greater than 20 m and less than 50 m, with infrequent representation outside that range (Figure 3). Estimates were mainly associated with the recreational fishing sector or with methods and gear commonly used in recreational fishing, and the only estimates for the commercial fishing sector came from a single study. Hook type estimates were fairly evenly split between those using J hooks and those using circle hooks with fewer studies using a mixture of hooks. Studies that showed a mixture of hook types were most commonly associated with studies that were directly observing the fishery and gear choice was therefore reflective of common fishing practices. Studies that were 100% compliant with venting practices were always associated with controlled scientific experiments (i.e. not direct observations of the fishery). Intermittent venting and non-venting values were most frequently associated with values derived from directly observing fishing practices aboard working vessels regardless of the fishing sector.

Release mortality estimates obtained by the meta-analysis showed significant effects of depth, fishing sector (commercial or recreational), venting, season and mixed hook type (Table 2A). No significant difference was found between circle or J hook type or for intermittent venting. The model was refit with non-significant factors removed (Table 2B). In the final model, depth was the most important factor determining release mortality. The strength of the categorical factors influencing mortality can be determined from the model coefficients which indicate that fishing sector and the 'mixed' hook type were the most influential factors increasing mortality while venting and season were important in reducing mortality from the base level. The amount of heterogeneity in effect size from the mixed-model was estimated to be τ^2=0.27. Cochran's Q_E test for the mixed-model also shows significant residual heterogeneity (Q_E = 623.42, df = 63, $p < 0.0001$), indicating that the model did not fully explain the observed variation in release mortality estimates. Model predicted discard mortality rates by depth, mode, season and venting status are presented in Table 3. Average model predictions (equal weighting of the coefficients) and inputting a depth range of 10 to 200 m resulted in predicted mortality from 25 to 95% (Figure 4).

For input into the red snapper stock assessment model predictions were obtained by commercial and recreational mode with and without venting. In June of 2008 federal regulations (73 FR 5117) required the carriage of venting tools onboard vessels and their use when a fish showed signs of swimbladder distension. This regulation also required the use of circle hooks but as this factor was not found to be significant no effect was estimated. To approximate the effects that this regulation likely had on discard mortality rate we assumed that prior to 2008 no fish were vented and for 2008 and later all fish that needed venting were vented. This provided estimates of discard mortality by fleet and season, before/after the June 2008 regulation (Figure 5). For both the recreational and commercial fishing sectors, the full compliance with venting would predict significantly lower release mortality over all depths (Figure 5). Within the depth range where most fishing occurs (20-50 m) the pre-2008 estimates were relatively similar to the fixed inputs estimates used in SEDAR 7 (2005) (horizontal black lines in Fig. 5A,B; Commercial East: 71% and West 82%; Recreational 1981-1996: 27.5% and 1997:2002: 21%). For both the sectors predicted mortality rates were highest in the fall, followed by summer, spring, and then lowest in the winter (Figure 6).

Discussion

This analysis provides consistent, population-level release mortality estimates that account for critical factors of depth, season, fishing sector and release protocol across a broad range of different studies. These estimates of release mortality provide critical input for stock assessments that need to account for mortality of released fish. Previous assessments used fixed values that did not account for the strong depth, season or venting effects estimated in this study. Furthermore, derivation of a single point estimate for previous assessments required difficult decisions regarding which study to use or how to average estimates from differing studies to obtain a population-level response. The meta-analytic approach used here provides a useful means of combining the results of different studies while controlling for much of the heterogeneity in experimental protocols and treatment effects.

The mixed model approach where a random effect is estimated for each individual study provides a robust method of dealing with specific differences due to either experimental protocols or other intangible factors, while estimating discard mortality as a function of key factors of interest. The various differences in experimental protocol or other intangible differences represented nuisance factors for the estimation of an overall discard mortality rate. Nonetheless significant residual heterogeneity was observed in the model suggesting that there were likely other unquantified variables that influence release mortality.

Regardless of study methodology or season there was a consistent positive correlation between depth and release mortality estimates (Table 1, Figures 1, 2, 4, 5, and 6). Presence of a positive correlation between depth and mortality is frequently reported in the literature, and the relationship is thought to be primarily associated with injuries sustained during decompression, including gas bladder overexpansion/rupture, esophageal eversion, cloacal prolapse, exophthalmia, and gas infusion into vital organs (Davis 2002, Rummer and Bennett 2005, Hannah 2008). While depth was a consistent factor explaining release mortality, the results were complicated by experimental methods chosen within studies and season. Few studies incorporated a wide range of depths or sampled quarterly, and none used multiple methods of determining release mortality.

Both sector and season were significant factors affecting release mortality. Sector was clearly the most influential factor which was likely due to the differences in how fish are captured in recreational versus commercial fishing gear. Commercial handline gear generally uses either electric or hydraulic gear where the fish are brought up from depth rapidly which may result in increased trauma. As season is a rough proxy for water temperature, the data suggest a positive relationship between water temperature and mortality. Sub-lethal types of responses, such as impairment scaling metrics, also show similar relationships with water temperature (Diamond and Campbell 2009, Campbell et al. 2010a, Campbell et al. 2010b), and impairment in at least two of those studies was linked to increased immediate release mortality. Tagging data has shown lowest returns from fish tagged during summer and highest from fish tagged during the winter (Sauls 2012, Diamond 2011), although tag-recapture studies are heavily influenced by the timing of the primary effort in the fishery (i.e. winter fishing effort is low and may result in less recaptures during that time). Finally, three projects that required field collections prior to proceeding with laboratory investigations, reported an inability to keep fish alive during collection or transport back to a laboratory during summer months (Parker 1985, Burns 2004, Campbell 2010a). Most investigations included in the meta-analysis had well defined depth treatments but had vaguely defined seasonal classifications, some report months, and only one reported specific water temperatures and thermocline strength. This complicates information from transitional seasons such as fall, because September water temperatures in the Gulf of Mexico are often more reflective of summer conditions. Evidence of unexplained residual heterogeneity in the mixed-model might be associated with insufficient treatment of these thermal components and so future studies should focus significant attention on this relationship.

The effect of venting also substantially reduced mortality. In lieu of finding ways to reduce catch of undersized fish, gas bladder venting is often advocated as a method to reduce the negative impacts of barotrauma. Our analysis suggests that venting lowers immediate release mortality rates as the 100% venting treatment was significant. Introducing a 100% venting treatment reduced predicted release mortality across all depths and in both fishing sectors. Venting clearly enhances submergence ability and therefore the observed differences are likely associated with the frequency of venting, or compliance with recently implemented venting regulations. Assuming no venting prior to 2008 and 100% compliance from 2008 onward allows for model predictions of discard mortality rates in both sectors of the red snapper fishery before and after 2008 when venting regulations were put in place (Figure 5). However, fishery observer data collected from recreational hook-and-line fisheries in the eastern Gulf of Mexico, where the fishery operates in relatively shallow depths, indicate that many fishers choose not to vent and that many fish released without venting are able to successfully re-submerge (Sauls, unpublished data). Furthermore, while venting has been shown to improve submergence capabilities, the effect on long-term survival may be negligible (Wilde 2009) and it is possible that this study overestimated the impact of venting as vented fish were more likely to sink and be presumed to have survived solely based on surface observations. There is a fundamental need for improved long-term fishery-dependent monitoring programs that collect higher resolution data on where and how the fishery operates with regards to discards.

Recent research has focused attention on bottom-release devices, two of which have been experimentally tested. The concept of using a bottom release device is similar to venting in that the goal is to reverse the effects of barotrauma, but instead of deflating the bladder by puncture it is deflated by recompression at depth. Diamond et al. (2011) tested a Shelton Fish Descender™, and results showed that the bottom release device did not improve survival over fish vented and released at the surface. Stunz and Curtis (2012) have tested a device that releases fish at a preset depth via a pressure sensitive clamp and results indicate that fish released using the device are more likely to survive than those vented and released at the surface. At this point it is difficult to discern if the differences between these two experiments were due to the gear used or some other effect. More studies are need to determine if there is some potential for bottom release devices to further enhance post-release survival or if the damage is essentially done and the effects of barotrauma cannot be reversed.

This study did not find a significant reduction in mortality due to circle hooks. This finding is surprising given that the regulation requiring circle hooks was put into place to reduce discard mortality by reduction in the frequency of gut hooking. However any effects of circle hooks or discard mortality may have been confounded in this study with fishing sector as no commercial study used J hooks and a very large amount of recreational studies used a mixture of hooks as well as a variety of venting practices. Hence our ability to estimate an effect of circle hooks separate from the commercial versus recreational effects may have been diminished. We do not necessarily think that circle hooks have no positive benefits, we simply may not have had the ability to detect it from the available studies. Nonetheless there is substantial documentation indicating that there are positive survival benefits of circle hooks (Cooke & Suski 2004).

Due to their prevalence in the literature, surface release estimates were the most common type included in this meta-analysis (Table 1, Figure 1), and historically are the most influential type used in assessing the red snapper population. Surface observations are useful due to the ability to obtain direct observations within a fishery, low operational costs, minimal equipment requirements, and the ease with which large sample sizes can be generated. Limitations of the method center on its observational nature. For instance, unsuccessful submergence is only a proxy of mortality, release behavior is subjective, observations are immediate (<1 minute), and unequivocal sub-surface observations are rare. Surface observations also ignore issues associated with CAR fishing such as hooking injuries, thermal stress, and barotrauma that could result in mortality over hours to days (Campbell et al. 2010a). As noted above, total discard mortality may be underestimated in this study as most studies used surface mortality observations. Finally, using immediate release mortality estimates from surface observations in an assessment requires that the estimate accurately reflects day-to-day fishing practices and likely should be independently determined for each sector (e.g. recreational and commercial). There is a large difference between a scientifically controlled experiment in which scientists vent 100% of the released fish, and an observational study where participants in a fishery inconsistently vent fish or did not vent fish at all.

Barotrauma injuries do not necessarily result in death, particularly as measured by immediate metrics (surface release observation), however data from studies estimating delayed mortality would suggest there is substantial mortality taking place hours to days following release (Diamond and Campbell 2009, Diamond et al. 2011). The variable ‘delayed’ was not significant however this could be due to the fact that there were few studies available. The other possibility is that while delayed studies generally show high release mortality there were plenty of surface release studies that showed similarly high responses. Two surface release studies, in particular, showed high release mortality but those responses were likely a result of little or no venting taking place during those observations (Dorf 2003, Nieland et al. 2007).

A separate issue with many of the acoustic tagging or caging studies is that they are typically sample size limited. With one exception the cage studies evaluated in this study had depth specific sample sizes between 10 and 56 (Parker 1985, Gitschlag and Renaud 1994, Render and Wilson 1994, Diamond and Campbell 2009), which is important because proportions are unstable at low sample sizes. For instance, at a sample size of 10 a change in the status of one fish equals a ten percent change in the estimate, and at a sample size of 50 a change in the status of five fish equals a ten percent change in the estimate. Diamond and Campbell (2009) show some of the highest estimates in the literature but were confounded by three important factors including hot surface water temperatures during summer sampling (~ 32.2 - 33.3°C), fish were placed in collapsed cages at the surface for extended periods before descent, and fish included in the experiment had blood drawn from them to evaluate stress physiology parameters. While cage studies show high mortality estimates, sample size and methodology appear to cloud the overall picture coming from some of these sources.

In passive tagging surveys, large numbers of fish must be tagged in order to evaluate survival because recapture rates are typically low (<10%). Only one of the passive tagging studies evaluated here produced estimates using a tag-and-recapture model (Sauls 2012) while the other two made use of surface observation methods (Patterson et al. 2001, Patterson and Addis personal communication). Recent developments have shown promise in using recapture and impairment scaling data to calculate relative survival from risk ratio models (Hueter et al. 2006, Sauls 2012). Continued development of tag-and-recapture models would be useful because they potentially avoid the biases associated with immediate estimators, and other delayed estimators. Another positive feature of tag-recapture models is that there is an abundance of tagging data available from the red snapper fishery if appropriate models are developed. Acoustic or satellite tags give the ideal level of information, but the expense of tags and required monitoring systems results in small sample sizes and poor power to estimate mortality. Diamond et al. (2011) reported some of the highest delayed release mortality estimates from an acoustic tagging project (winter - 40%, and summer - 79%), but had very low sample sizes (~ 40 total fish), and required surgery to implant tags which could have biased the results. Until better and more cost effective technology is developed, derivation of mortality estimates from experiments using acoustic tags will likely be limited.

Methods that relate impairment to mortality have proven to be effective estimators of release mortality for many species including walleye pollock (*Theragrachalcogramma*, Gadidae), coho salmon (*Oncorhynchus kisutch*,Salmonidae), sablefish (*Anoplopoma fimbria*, Anoplopomatidae), northern rock sole (*Lepidopsetta polyxystra*,Pleuronectidae), lingcod (*Ophiodon elongates*, Hexagrammidae), Pacific halibut (*Hippoglossus stenolepis*,Pleuronectidae), and red snapper (Davis et al. 2001, Davis and Ottmar 2006, Davis 2007, Campbell 2010a, Campbell 2010b). Impairment scaling metrics have consistently shown a logistic type functional relationship with mortality. The barotrauma-reflex (BtR) impairment scaling metric showed positive correlation between impairment level and immediate mortality in the recreational red snapper fishery but is hampered because it relied on an immediate estimate (Campbell 2010a). Impairment scaling methods were back-applied to a cage study that collected a limited amount of barotrauma data, and also showed a significant relationship with delayed estimates of mortality in the red snapper fishery (Diamond and Campbell 2009). Given that impairment scaling studies have shown significant relationships to release mortality in both the immediate and cage studies these techniques might prove to be useful to inform tag-and-recapture models that are being developed.

Conclusions

There have been significant improvements in understanding release mortality in general and particularly in the red snapper fishery. Despite the significant efforts of many researchers, fundamental biases still persist in the various approaches. Immediate estimates do not address long term effects of barotrauma, do not account for predation, and rely on proxies to calculate mortality rates. Delayed estimates have been plagued with small sample sizes, cost prohibitive designs, excessive handling, and failure to duplicate normal fishing conditions. Focusing on increasing sample sizes in acoustic tagging surveys, and continued improvement of tag-and-recapture models would be useful. Passive tagging and acoustic tagging appear to offer good solutions because they can measure both immediate and delayed mortality components and fish handling biases can be minimized particularly as technology improves and costs are brought down. Experiments estimating impairment scaling, and both immediate and delayed mortality, would also be useful so that those relationships could be developed and historical estimates could potentially be adjusted. Future surveys should include some if not all of the following properties including quarterly sampling, appropriate range of depths, water temperature and thermocline data rather than 'seasonal' categorization, tag-and-recapture modeling, and barotrauma and reflex responses.

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Table 1. List of studies from the Gulf of Mexico reporting red snapper release mortality estimates (Mort.) by 5 m depth groups (Dep.). Type: SR=surface release, C=cage, PT=passive tagging, AT=acoustic tagging. Timing: I=immediate, D=delayed. Sector (Sec.): Rec=recreational, Com=commercial. Season (Seas.): Sum=summer, Spr=spring, Win=winter, Fall=fall, Ann=annual. Hook: C=circle hooks, J=j hooks. Vent: V=100% venting, IV=intermittent venting, NV=no venting.

Dep.	**Mort.**	**Type**	**Timing**	**Sec.**	**Seas.**	**Hook**	**Vent**	***N***	**Study**	**Year**
10	0.280	SR	I	Rec	Sum	J	NV	25	Dorf	2003
10	0.700	SR	I	Com	Win	C	NV	40	Nieland	2007
15	0.282	SR	I	Rec	Sum	J	NV	425	Dorf	2003
20	0.273	SR	I	Rec	Sum	J	NV	825	Dorf	2003
20	0.252	SR	I	Com	Win	C	NV	465	Nieland	2007
21	0.090	SR	I	Rec	Ann	J	V	1064	Patterson	2001
22	0.210	C	D	Rec	Ann	J	V	14	Parker	1985
24	0.010	SR	I	Rec	Fall	J	NV	140	Gitschlag Renaud	1994
25	0.200	C	D	Rec	Ann	J	V	282	Render Wilson	1994
25	0.410	SR	I	Rec	Sum	J	NV	525	Dorf	2003
25	0.280	PT	D	Rec	Sum	C	IV	353	Sauls	2012
25	0.260	PT	D	Rec	Sum	C	IV	353	Sauls	2012
25	0.230	PT	D	Rec	Fall	C	IV	353	Sauls	2012
25	0.160	PT	D	Rec	Fall	C	IV	353	Sauls	2012
25	0.290	PT	D	Rec	Win	C	IV	353	Sauls	2012
25	0.250	PT	D	Rec	Win	C	IV	353	Sauls	2012
25	0.170	PT	D	Rec	Spr	C	IV	353	Sauls	2012
25	0.180	PT	D	Rec	Spr	C	IV	353	Sauls	2012
27	0.140	SR	I	Rec	Ann	J	V	856	Patterson	2001
30	0.110	C	D	Rec	Ann	J	V	30	Parker	1985
30	0.100	SR	I	Rec	Fall	J	NV	31	Gitschlag Renaud	1994
30	0.420	C	D	Rec	Sum	M	V	47	Diamond Campbell	2009
30	0.130	C	D	Rec	Fall	M	V	30	Diamond Campbell	2009
30	0.470	SR	I	Rec	Sum	J	NV	225	Dorf	2003
30	0.213	SR	I	Rec	Fall	C	V	137	Campbell	2010
30	0.227	SR	I	Rec	Sum	C	V	137	Campbell	2010
30	0.030	SR	I	Rec	Win	J	V	138	Patterson Addis	2007
30	0.060	SR	I	Rec	Spr	J	V	31	Patterson Addis	2007
30	0.070	SR	I	Rec	Sum	J	V	52	Patterson Addis	2007
30	0.120	SR	I	Rec	Fall	J	V	221	Patterson Addis	2007
30	0.681	SR	I	Com	Win	C	NV	789	Nieland	2007
32	0.180	SR	I	Rec	Ann	J	V	1012	Patterson	2001
35	0.150	SR	I	Rec	Sum	J	NV	100	Dorf	2003
35	0.040	SR	I	Rec	Win	J	V	375	Patterson Addis	2007
35	0.100	SR	I	Rec	Spr	J	V	196	Patterson Addis	2007
35	0.130	SR	I	Rec	Sum	J	V	264	Patterson Addis	2007
35	0.170	SR	I	Rec	Fall	J	V	563	Patterson Addis	2007
35	0.370	PT	D	Rec	Sum	C	IV	863	Sauls	2012
35	0.330	PT	D	Rec	Sum	C	IV	863	Sauls	2012
35	0.280	PT	D	Rec	Fall	C	IV	863	Sauls	2012
35	0.220	PT	D	Rec	Fall	C	IV	863	Sauls	2012
35	0.220	PT	D	Rec	Win	C	IV	863	Sauls	2012

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35	0.120	PT	D	Rec	Win	C	IV	863	Sauls	2012
35	0.230	PT	D	Rec	Spr	C	IV	863	Sauls	2012
35	0.210	PT	D	Rec	Spr	C	IV	863	Sauls	2012
40	0.440	SR	I	Rec	Fall	J	NV	61	Gitschlag Renaud	1994
40	0.400	SR	I	Rec	Sum	J	NV	155	Dorf	2003
40	0.050	SR	I	Rec	Win	J	V	65	Patterson Addis	2007
40	0.160	SR	I	Rec	Spr	J	V	107	Patterson Addis	2007
40	0.160	SR	I	Rec	Sum	J	V	44	Patterson Addis	2007
40	0.200	SR	I	Rec	Fall	J	V	60	Patterson Addis	2007
40	0.420	C	D	Rec	Sum	M	V	56	Diamond Campbell	2009
40	0.340	C	D	Rec	Fall	M	V	32	Diamond Campbell	2009
40	0.740	SR	I	Com	Win	C	NV	814	Nieland	2007
45	0.630	SR	I	Rec	Sum	J	NV	280	Dorf	2003
50	0.360	C	D	Rec	Fall	J	IV	55	Gitschlag Renaud	1994
50	0.690	C	D	Rec	Sum	M	V	24	Diamond Campbell	2009
50	0.440	C	D	Rec	Fall	M	V	36	Diamond Campbell	2009
50	0.610	SR	I	Rec	Sum	J	NV	105	Dorf	2003
50	0.790	AT	D	Rec	Sum	M	V	24	Diamond	2011
50	0.400	AT	D	Rec	Win	M	V	20	Diamond	2011
50	0.744	SR	I	Com	Win	C	NV	1638	Nieland	2007
55	0.580	SR	I	Rec	Sum	J	NV	240	Dorf	2003
60	0.380	SR	I	Rec	Sum	J	NV	125	Dorf	2003
60	0.214	SR	I	Rec	Fall	C	V	282	Campbell	2010
60	0.258	SR	I	Rec	Sum	C	V	282	Campbell	2010
60	0.694	SR	I	Com	Win	C	NV	464	Nieland	2007
65	0.370	SR	I	Rec	Sum	J	NV	50	Dorf	2003
70	0.330	SR	I	Rec	Sum	J	NV	10	Dorf	2003
70	0.782	SR	I	Com	Win	C	NV	404	Nieland	2007
75	0.230	SR	I	Rec	Sum	J	NV	75	Dorf	2003
80	0.470	SR	I	Rec	Sum	J	NV	100	Dorf	2003
80	0.886	SR	I	Com	Win	C	NV	88	Nieland	2007
90	0.912	SR	I	Com	Win	C	NV	68	Nieland	2007
95	0.560	SR	I	Rec	Sum	J	NV	30	Dorf	2003

Type: SR=surface release , C=cage, PT=passive tagging, AT=acoustic tagging
Timing: I=immediate, D=delayed
Sector: Rec=recreational,
Com=commericial
Season: Sum=summer, Spr=spring, Win=winter, Fall=fall, Ann=annual
Hook: C=circle hooks, J=j hooks
Vent: V=100% venting, IV=intermittent venting, NV=no venting

Table 2. Model coefficients

A. Initial model with all terms

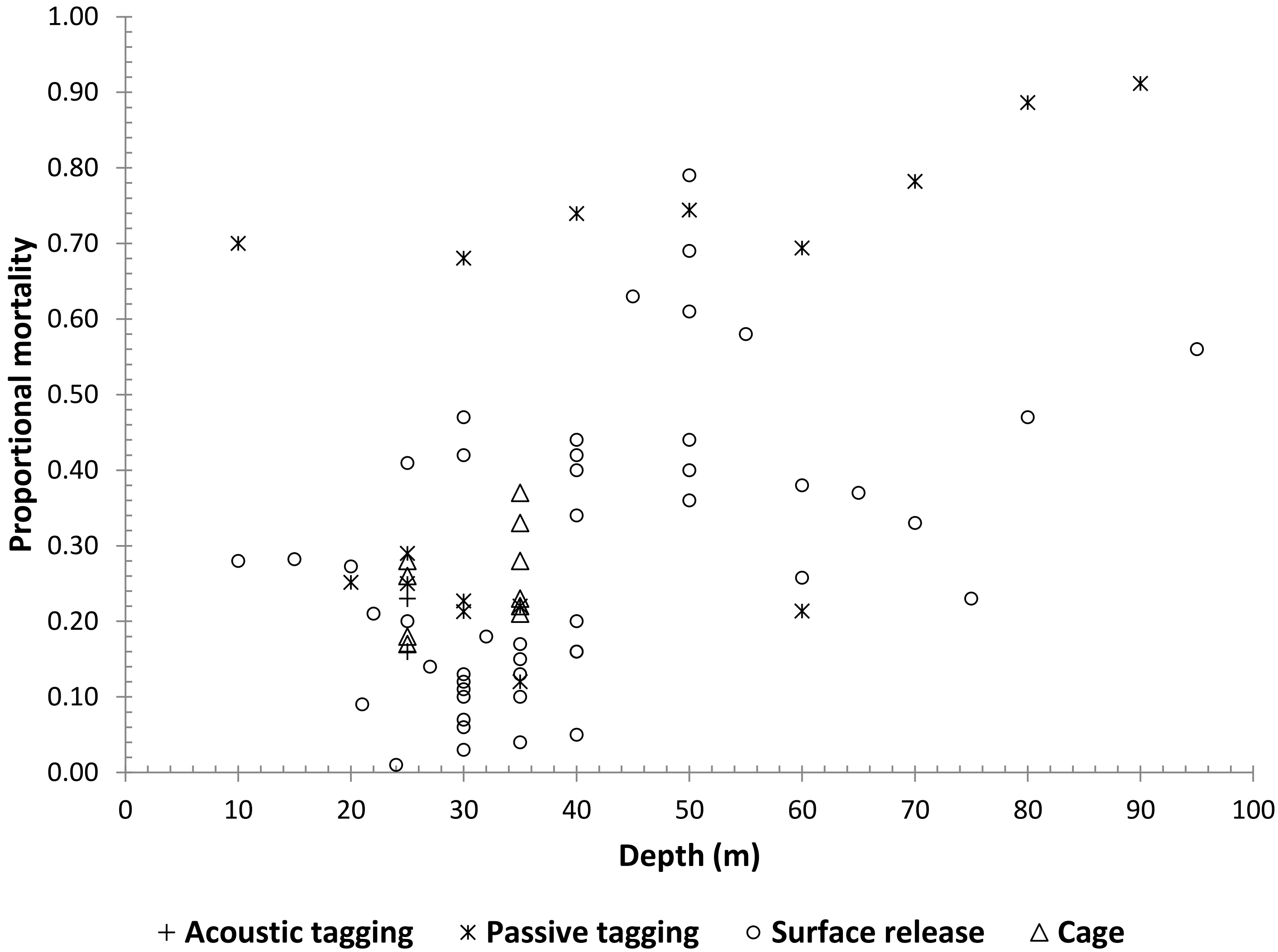
	Coefficient	SE	Z	P-value	Significant
intercept	-1.3919	0.2421	-5.7505	<.0001	*
Depth	0.0201	0.0044	4.5723	<.0001	*
Commercial	1.7278	0.4805	3.5956	0.0003	*
Delayed	0.3505	0.499	0.7025	0.4824	ns
Vent	-0.9439	0.2563	-3.6825	0.0002	*
Intermediate vent	-0.7564	0.6307	-1.1992	0.2304	ns
Winter	-0.9117	0.2688	-3.3922	0.0007	*
Spring	-0.6441	0.2798	-2.3023	0.0213	*
Fall	-0.4313	0.2048	-2.1063	0.0352	*
Annual	-0.0793	0.3842	-0.2065	0.8364	ns
Circle	0.5265	0.2946	1.787	0.0739	ns
Mixed	1.228	0.5823	2.1089	0.035	*

B. Final model with non-significant terms removed.

	Coefficient	SE	Z	P-value	Significant
intercept	-1.3523	0.2001	-6.7570	<0.001	*
Depth	0.0201	0.0041	4.8775	<0.001	*
Commercial	2.1953	0.2911	7.5406	<0.001	*
Vent	-0.8646	0.1589	-5.4401	<0.001	*
Winter	-0.8942	0.2320	-3.8537	<0.001	*
Spring	-0.6313	0.2400	-2.6309	0.0085	*
Fall	-0.4011	0.1786	-2.2458	0.0247	*
Mixed	1.4451	0.2682	5.3881	<0.001	*

Table 3. Discard mortality estimates by sector, venting status and season

	Recreational								Commercial							
	Winter		Spring		Summer		Fall		Winter		Spring		Summer		Fall	
Depth	NV	V	NV	V	NV	V	NV	V	NV	V	NV	V	NV	V	NV	V
0	0.21	0.10	0.10	0.04	0.12	0.05	0.15	0.07	0.70	0.49	0.49	0.29	0.55	0.34	0.61	0.40
10	0.22	0.11	0.10	0.05	0.13	0.06	0.16	0.07	0.72	0.52	0.51	0.31	0.58	0.37	0.63	0.42
20	0.24	0.12	0.11	0.05	0.14	0.07	0.17	0.08	0.74	0.54	0.54	0.33	0.60	0.39	0.66	0.44
30	0.26	0.13	0.13	0.06	0.16	0.07	0.19	0.09	0.76	0.57	0.56	0.35	0.63	0.41	0.68	0.47
40	0.28	0.14	0.14	0.06	0.17	0.08	0.21	0.10	0.78	0.59	0.59	0.37	0.65	0.44	0.70	0.49
50	0.30	0.15	0.15	0.07	0.19	0.09	0.22	0.11	0.79	0.62	0.61	0.40	0.67	0.46	0.72	0.52
60	0.32	0.17	0.16	0.08	0.20	0.10	0.24	0.12	0.81	0.64	0.63	0.42	0.69	0.49	0.74	0.54
70	0.34	0.18	0.18	0.08	0.22	0.10	0.26	0.13	0.82	0.66	0.66	0.45	0.71	0.51	0.76	0.57
80	0.37	0.20	0.19	0.09	0.24	0.11	0.28	0.14	0.84	0.69	0.68	0.47	0.73	0.54	0.78	0.59
90	0.39	0.21	0.21	0.10	0.25	0.13	0.30	0.15	0.85	0.71	0.70	0.50	0.75	0.56	0.79	0.62
100	0.41	0.23	0.22	0.11	0.27	0.14	0.32	0.17	0.86	0.73	0.72	0.52	0.77	0.59	0.81	0.64
110	0.44	0.25	0.24	0.12	0.29	0.15	0.34	0.18	0.88	0.75	0.74	0.55	0.79	0.61	0.82	0.66
120	0.46	0.27	0.26	0.13	0.31	0.16	0.37	0.20	0.89	0.77	0.76	0.57	0.80	0.63	0.84	0.69
130	0.49	0.29	0.28	0.14	0.34	0.18	0.39	0.21	0.90	0.78	0.78	0.60	0.82	0.66	0.85	0.71
140	0.51	0.31	0.30	0.15	0.36	0.19	0.41	0.23	0.90	0.80	0.79	0.62	0.83	0.68	0.86	0.73
150	0.54	0.33	0.32	0.17	0.38	0.21	0.44	0.25	0.91	0.82	0.81	0.64	0.85	0.70	0.88	0.75
160	0.56	0.35	0.35	0.18	0.41	0.22	0.46	0.27	0.92	0.83	0.83	0.67	0.86	0.72	0.89	0.77
170	0.59	0.38	0.37	0.20	0.43	0.24	0.49	0.29	0.93	0.84	0.84	0.69	0.87	0.74	0.90	0.78
180	0.61	0.40	0.39	0.21	0.46	0.26	0.51	0.31	0.93	0.86	0.85	0.71	0.88	0.76	0.90	0.80
190	0.64	0.42	0.42	0.23	0.48	0.28	0.54	0.33	0.94	0.87	0.86	0.73	0.89	0.78	0.91	0.82
200	0.66	0.45	0.44	0.25	0.51	0.30	0.56	0.35	0.95	0.88	0.88	0.75	0.90	0.80	0.92	0.83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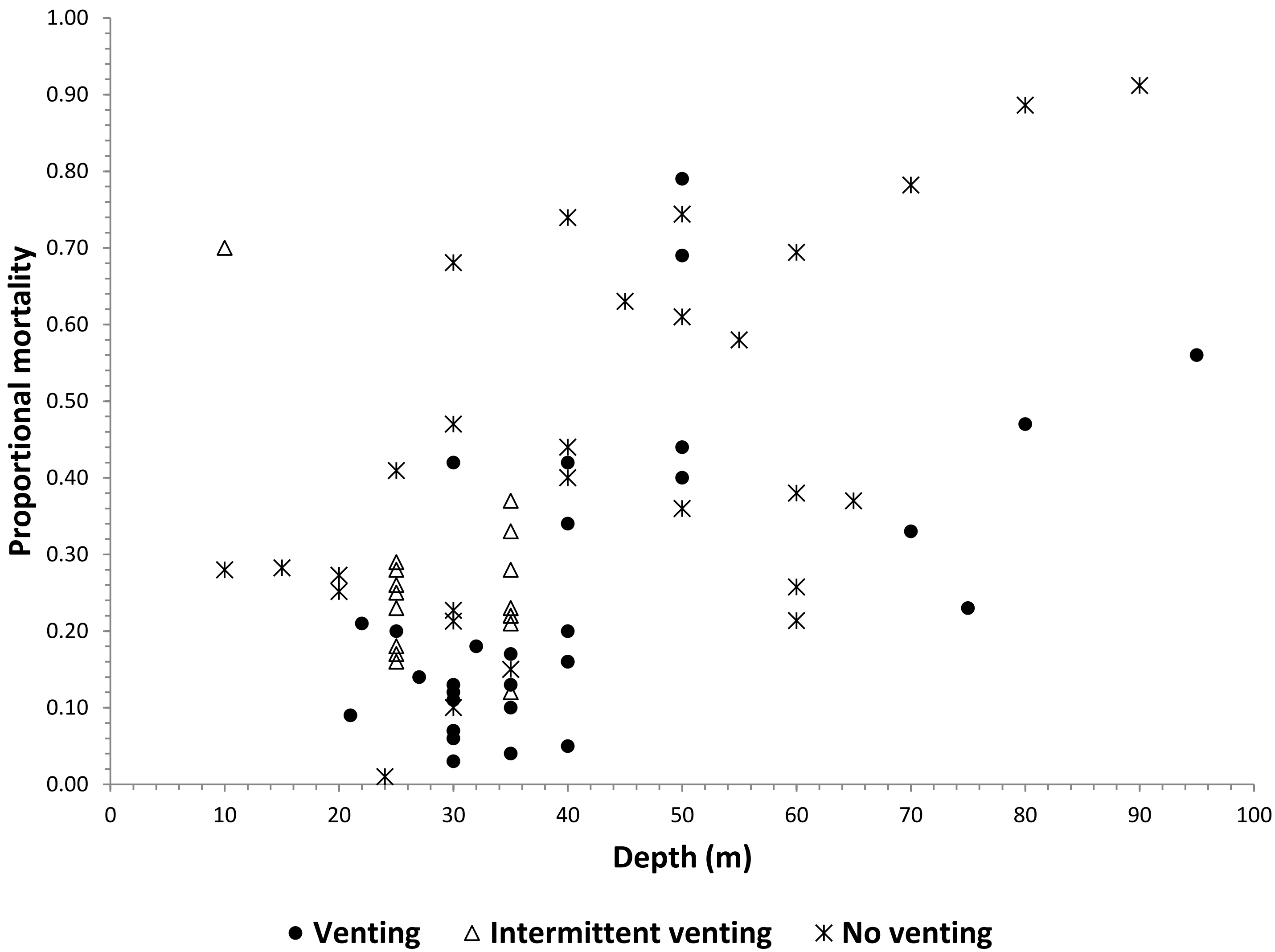
90
100
Depth (m)
Acoustic tagging
Passive tagging
Surface release
Cage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Venting
Intermittent venting
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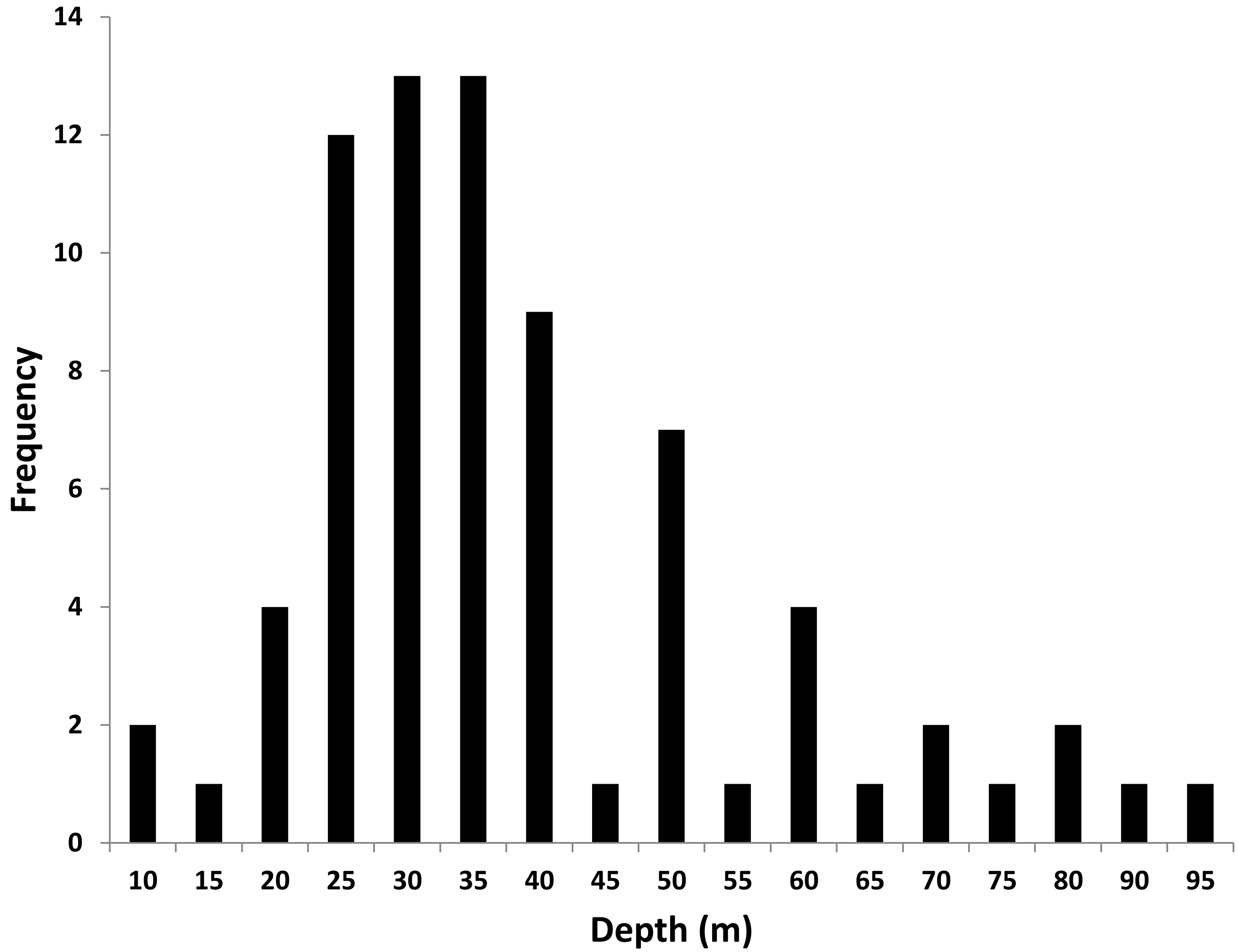
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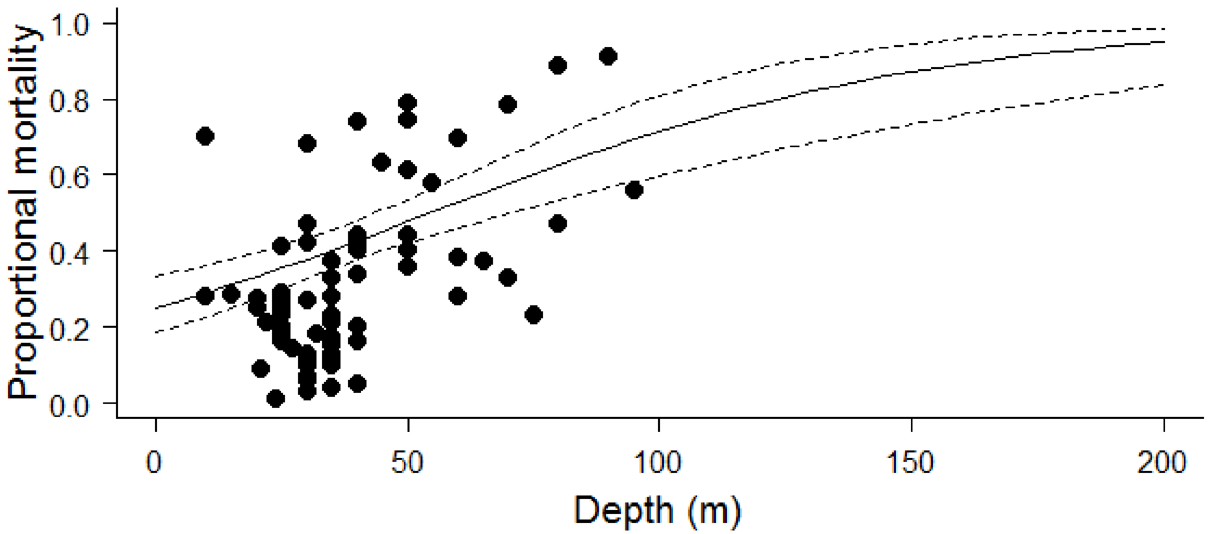
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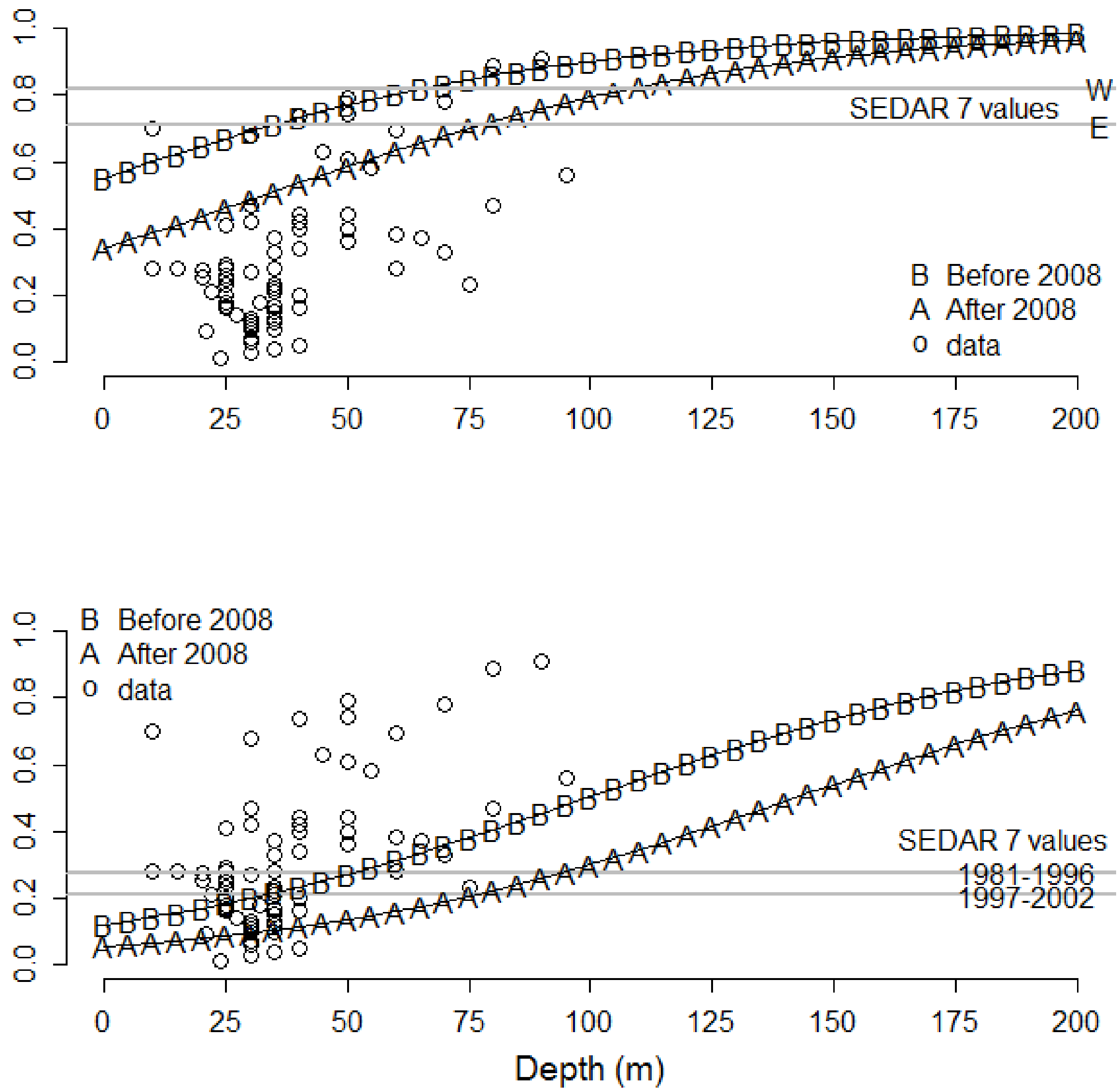
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o data
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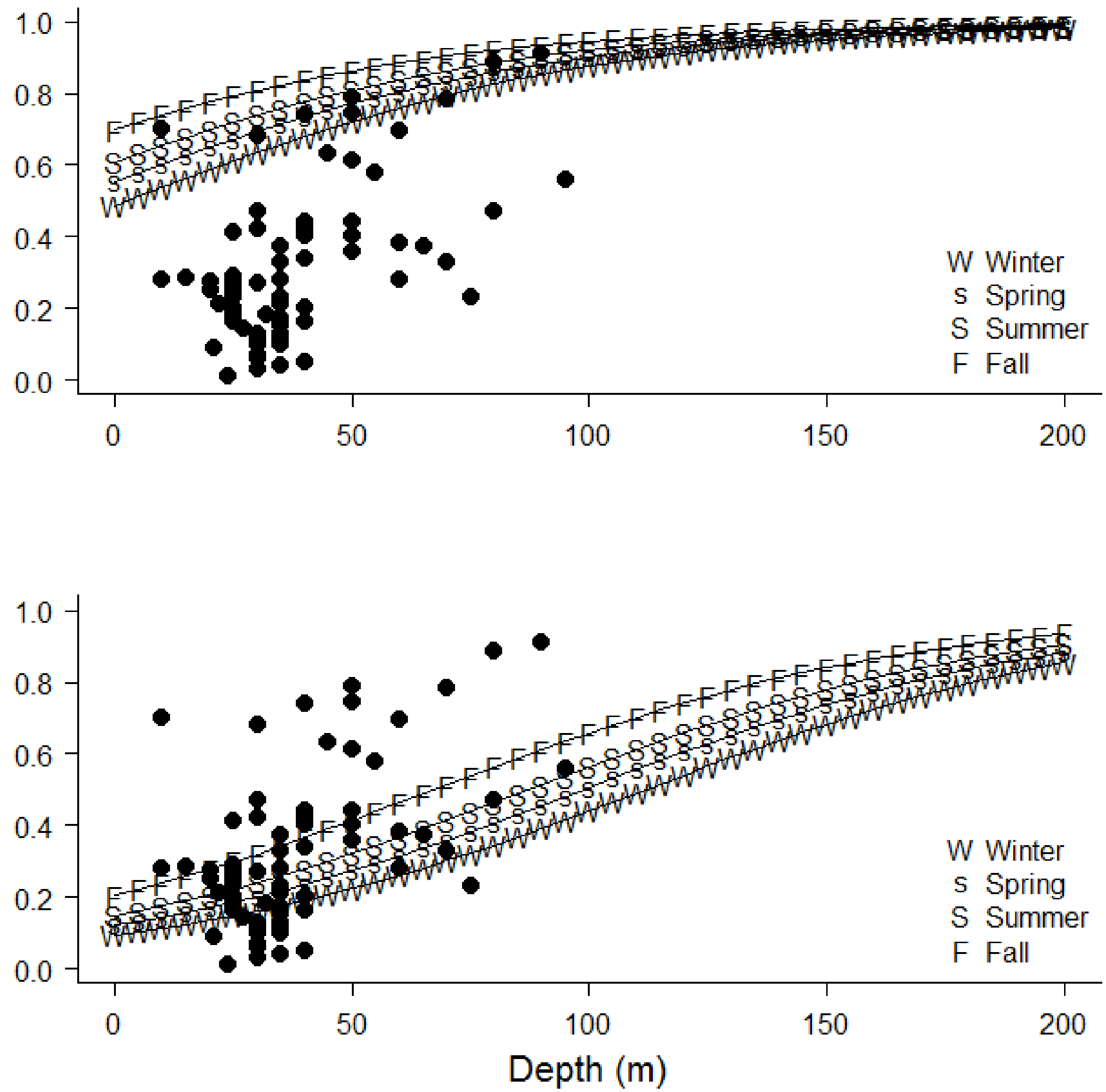
1981-1996
1997-2002
Depth (m)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