Fisheries Research 106 (2010) 64–70

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Relating angling-dependent fish impairment to immediate release mortality of red snapper (*Lutjanus campechanus*)

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ARTICLE INFO

Article history:
Received 18 March 2010
Received in revised form 11 June 2010
Accepted 14 July 2010

Keywords:
Impairment
Condition index
Release mortality
Predation
Barotrauma
Reflex response
Red snapper

ABSTRACT

Catch-and-release (CAR) fishing of deep-water physoclistous species can lead to increased stress and impairment often resulting in immediate release mortality. We made use of a condition index (BtR score) to evaluate the relationship between CAR-related impairment and immediate release mortality in the recreational red snapper (*Lutjanus campechanus*) fishery. Symptoms of barotrauma and impairment showed positive relationships with capture depth and occurred more frequently during the summer sampling than the fall. Impairment, as measured by BtR score, showed significant logistic relationships with immediate release mortality proxies such as floating and erratic swimming at release. Logistic curves had inflection points at BtR scores of 0.3–0.4 (on a scale of 0–1), above which fish experienced high immediate release mortality regardless of season (60–100%). Mean BtR scores were lower than the inflection point of the logistic curve, resulting in immediate release mortality estimates ranging from 20% to 28%. Recaptured fish showed significantly lower impairment than non-recaptured fish. The BtR score is a proficient method to estimate both impairment and immediate release mortality of red snapper in field settings.

1. Introduction

Catch-and-release (CAR) fishing exposes fish to a series of events that elevates stress and potentially causes release mortality, particularly for deep-water physoclistous species (Rummer and Bennett, 2005; Nieland et al., 2007; Jarvis and Lowe, 2008). These CAR fishing stressors can also translate into long-term, sub-lethal, negative consequences for individuals and populations, such as reduced growth, fecundity, and survival (Woodley and Peterson, 2003; Ryer et al., 2004; Davis, 2007). Stressors experienced during CAR fishing can include hooking, struggling to exhaustion, barotraumas, rapid thermal change (thermocline), air exposure, and physical handling (Davis and Olla, 2001; Rummer and Bennett, 2005).

Red snapper (*Lutjanus campechanus*) in the Gulf of Mexico (GOM) have been classified as overfished by the Gulf of Mexico Fishery Management Council (GMFMC) and the National Marine Fisheries Service (NMFS) since 1984 (Goodyear and Phares, 1990). In response to overfishing management regulations have been imposed in the fishery and included size limits, bag limits, and closed seasons (Manooch et al., 1998; Schirripa and Legault, 1999; SEDAR 7, 2004). Each of these strategies effectively results in a CAR fishery as well as uncertainty in the amount of associated release mortality. When discard rates in a catch-and-release (CAR) fishery are high, release mortality can represent a critical source of uncertainty when estimating vital population rates useful for stock assessments (Davis, 2002).

Quantifying mortality associated with CAR fishing is problematic due to logistical issues associated with tracking released fish in expansive marine environments over immediate (minutes) or delayed (days–months) time frames. Immediate release mortality in the recreational red snapper fishery in the past has been estimated by observing the frequency of release activities such as floating and erratic swimming that can be thought of as proxies of mortality (Dorf, 2003). Observing fish behavior at release, while useful, ignores potential relationships between stress, impairment, and release mortality associated with CAR fishing. Knowledge about the underlying causality is equally if not more important because knowing the source of the problem potentially leads to solutions rather than simple recognition of a problem and furthermore, any improvement in estimation of release mortality estimates (immediate and delayed) is beneficial.

Synergistic approaches that combine behavioral, physiological and reflex responses have shown potential in estimating stress, impairment and release mortality associated with CAR fishing in both laboratory (simulated) and field settings. The reflex action mortality predictor (RAMP) was developed to analyze the effects

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doi:10.1016/j.fishres.2010.07.004

of capture and thermal stress on several species of Pacific groundfish and consistently demonstrates a sigmoidal relationship with total release mortality observed in the laboratory (Davis, 2007). A modified version of the RAMP score called barotrauma reflex score (BtR) was designed to scale impairment associated with CAR fishing of red snapper and was tested under laboratory conditions (Campbell et al., 2010). Impairment (increased BtR) of red snapper was positively related to treatment depth, water temperature, and plasma cortisol level, and was negatively related to swimming speed, approach distance and reaction time to a simulated predator. A reduced version of the BtR score constructed from historic discard data showed significant correlation with delayed mortality (Diamond and Campbell, 2009).

The ability of fish to perform normal behaviors and to be inconspicuous relative to conspecifics is important because vulnerable and conspicuous individuals are often preferred over less vulnerable counterparts (Ellis and Gibson, 1997; Scharf et al., 1998; Domenici, 2001; Stankovich, 2003). Impairment due to CAR fishing effectively isolates individuals and creates a state of vulnerability that could lead to preferential selection as potential prey. In a laboratory setting, sablefish (*Anoplopoma fimbria*) stressed by simulated trawling, experienced significantly higher predation rates than did controls, but were comparable after a 2-h recovery period (Ryer et al., 2004). Impairment scaling metrics could be a promising tool to evaluate the relationship between CAR fishing and predation because they can relate CAR stress to relevant predator evasion behaviors. If a fish is unable to sense and react to a potential threat, it is less likely to survive a predator attack (Fuiman et al., 2006). In the northwestern Gulf of Mexico, Atlantic bottlenose dolphin (*Tursiops truncatus*) and barracuda (*Sphyraena barracuda*) are frequently observed on both artificial and natural reefs (Rooker et al., 1997; Waring et al., 2005), and are often seen feeding on released red snapper. Because capture stress has been shown to increase impairment, and predation at release sites is frequently observed it is important to investigate the predation component of release mortality.

Goals of the study were to estimate BtR scores under field conditions, and investigate the functional relationship between BtR and sources of immediate release mortality in the red snapper fishery. We hypothesized that: (1) field studies of impairment would show similar results to those found in laboratory settings, (2) impairment would show positive relationships with capture depth and season, (3) there would be a positive relationship between proxies of release mortality and impairment, (4) there would be a positive relationship between predation mortality and impairment, and (5) recaptured fish will show significantly lower impairment.

2. Methods

2.1. Capture and estimation of BtR scores

Daily sampling trips were taken from October 16–November 4, 2007 (11 trips) and July 8–17, 2008 (8 trips) to two oil production platform sites; MU-726A (27.8088N, 96.7814W, 30 m depth) and MU-784A (27.6566N, 96.5791W, 60 m depth). Red snapper were captured using standard fishing practices in the recreational fishery, measured (total length, cm), and analyzed for BtR symptoms utilizing methods developed by Campbell et al. (2010). Assessed barotraumas included tightened air bladder, stomach eversion, intestinal protrusion, exophthalmia, subcutaneous hemorrhaging, and non-induced activity level (tail flapping versus lethargic). Elicited reflex responses included gag, operculum, dorsal spine, vestibular–ocular, and tail muscle flex. Reflex tests took place out of the water with the fish restrained so that each test could be done in isolation. Calculation of BtR score proceeded as:

Table 1
Sample sizes by treatment group for fish evaluated for BtR, and for release activity of fish at release.

	BtR observations			Release activity observations		
	30 m	60 m	Total	Surface		Total
				30 m	60 m	
Fall	155	292	447	89	139	228
Summer	93	282	375	48	143	191
Total	248	574	822	137	282	419

Treatment group sample sizes (*n*).

$$\text{BtR} = 1 - \left(\frac{\sum \text{Individual Responses}}{\text{Total Responses Possible}} \right) \quad (1)$$

A BtR score equal to 0 indicated a fish with no impairment, while a score equal to 1 indicated highest impairment. The BtR scoring procedure takes approximately the same amount of time it takes a deckhand to deal with a fish on a recreational vessel operating in the red snapper fishery (<1 min). It is unlikely that the procedure adds more handling stress than occurs in the recreational fishery as it is currently prosecuted. Treatment differences in field BtR scores were tested using two-way ANOVA where treatments were season and depth (sample sizes are listed in Table 1). Mean differences in BtR between recaptured and non-recaptured subjects were tested using a two-sample *t*-test pooled over seasons and depth treatments (SAS v 9.1.3, SAS Institute inc. Cary, NC, USA). Pooled data were used because of the low number of recaptures ($n = 22$).

2.2. Release observations

All fish were tagged (Floy™, Seattle, WA, USA), vented, and released on the surface. A randomly selected portion of the fish evaluated for BtR score were also evaluated for 1 min post-release for their ability to submerge ($n = 419$, Table 1), and the remaining fish were used to test a descending device in a separate experiment. Common practice in the recreational red snapper fleet is to 'vent' fish prior to release and was performed by inserting an 18 gauge syringe and needle from the ventral side of the fish into the air bladder until the bladder was deflated. Surface release observations followed protocols described in Dorf (2003) and Diamond and Campbell (2009). Surface release activities included: swimming directly downward (Sd), floating (Fl) and swimming erratically (E). If a subject was definitively consumed by a predator the observation was noted as (P). Swimming downward, erratic swimming and floating are mutually exclusive categories however predation is not. Any one of the three release activities could have been noted prior to predation occurring. Observational distance of surface-released fish was observer-dependent, unlimited in range, and upon submergence approximately 2 m in range depending on sea-state. Differences in mean frequency of release activity and predation were tested using two-way ANOVA where treatments were season and depth (SAS 9.1.3, SAS Institute inc. Cary, NC, USA) (see Table 1).

2.3. Release activity as proxies of immediate mortality

Immediate release mortality was estimated using six combinations of release activities and predation. Release activities are used as proxies of mortality and therefore do not necessarily represent actual mortality, while predation is known mortality. Group percent-mortality estimates were calculated for each discrete BtR score, for each separate sampling season. Immediate release mortality is defined as $1 - S$ ($S = \%$ survival), not instantaneous fishing mortality (F). Because there is differing opinions on which of

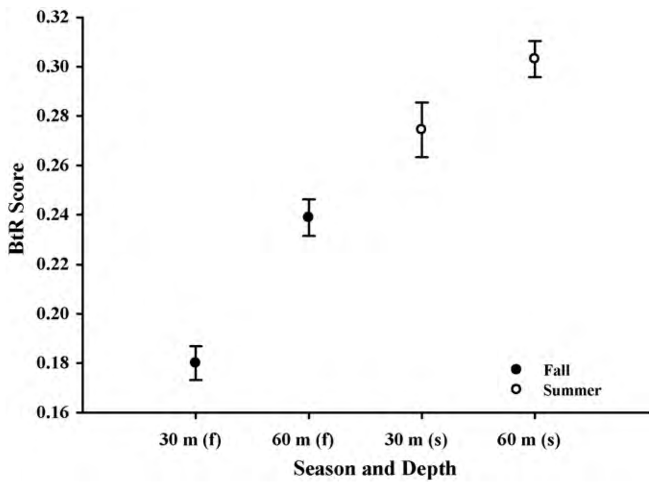

Fig. 1. *Lutjanus campechanus.* Mean BtR scores ± 1 se, estimated by season (fall and summer), and depth (30 and 60 m).

the activity proxies should be used to estimate release mortality we calculated six separate possibilities. The six combinations of release activity proxies used included the following: floating (Fl), erratic swimming (E), predation (P), floating + erratic (FE), floating + predation (FP), and floating + erratic + predation (FEP). When calculating release mortality for combinations that included predation, the release activity observed prior to the occurrence of predation was discarded to avoid double counting sources of mortality. While predation is not mutually exclusive from the release activities, it is treated as such because otherwise the numerator in the calculated proportion would be adding extra mortality that did not occur (i.e. adding an incidence of mortality to the numerator, but not increasing sample size in the denominator). The relationship between BtR and group percent mortality (by discrete BtR groups) was tested using a 4 parameter logistic regression model as:

$$y = y_0 + \left(\frac{a}{1 + (x/x_0)^b} \right) \tag{2}$$

where x_0, y_0, a, and b are logistic regression coefficients, x is BtR score, and y is percent mortality. If a logistic regression model for a combination (Fl, E, P, FE, FP, or FEP) was significant, then percent release mortality estimates (y) were calculated using logistic coefficients and mean BtR score from the associated sampling period (fall or summer). In addition a third group of percent release mortality estimates were calculated using logistic regression coefficients when both predation (fall) and BtR scores (summer) were highest (Sigma Plot 11.0, Systat Software Inc., San Jose, CA).

3. Results

3.1. Barotrauma—reflex response scoring (BtR)

Field estimates of the BtR score were similar to laboratory estimates, both showing positive relationships between impairment level and treatment depth. While the mean responses were similar, small sample sizes from the laboratory experiment ($n = 69$) resulted in higher variability than those estimated from Gulf of Mexico field sites ($n = 822$). Field data showed increased impairment (increased BtR) with increasing depth and higher scores during the summer sampling period as compared to the fall (Fig. 1). There were significant differences in BtR score by depth ($F_{1,818} = 69.6$, $p < 0.001$) and by season ($F_{1,818} = 23.89$, $p < 0.001$). There was a significant difference in mean BtR between recaptured and non-recaptured fish ($t_{780} = 2.45$, $p = 0.014$). Mean BtR for recaptured fish was lower (0.202, $n = 22$), than for non-recaptured fish (0.261, $n = 760$). More of the recaptures were tagged during the fall (17) than the summer (5).

3.2. Release activity and predation frequencies

Over the course of the experiment the least frequent release activity mortality proxy observed was erratic swimming (*E*, 5.6%), while the highest was floating (Fl, 19.3%, Fig. 2). The majority of the fish were able to swim immediately downward (SD, 75.1%). Analysis showed significant differences in the number of fish floating at release by depth group ($F_{1,418} = 7.37$, $p = 0.007$) while the season and the interaction effects were non-significant. More fish floated following release at the 60 m site than did at the 30 m site (Fig. 2). There were no significant differences in the number of fish swimming erratically by season, depth, or the interaction term.

Evaluation of the combinations of release activity proxies and predation shows similar depth effects and are primarily influenced by the frequency of floating. There were significant differences in FE frequency by depth ($F_{1,418} = 5.93$, $p = 0.015$) but none for the season or interaction terms. There were significant differences in frequency of FP by depth ($F_{1,418} = 11.9$, $p < 0.001$) and a significant interaction ($F_{1,418} = 6.08$, $p = 0.014$), but no difference by season. There were significant differences FEP frequency by depth ($F_{1,418} = 5.44$, $p = 0.02$) and a significant interaction ($F_{1,418} = 5.97$, $p = 0.015$), but no difference by season. For both the FP and the FEP combined release activity metrics, the significant interaction term is likely due to the high frequency of predation observed from the fall/60 m sample (Fig. 2).

Fish exhibited decreased ability to submerge with increasing BtR (Fig. 3), showing significant differences in BtR score by release activity ($F_{2,415} = 25.24$, $p < 0.001$), and season ($F_{1,415} = 37.85$, $p < 0.001$), but not the interaction term. Seasonal trends showed that BtR scores were lower in fall than summer for all release observation groups. During the fall fish that swam immediately downward had the lowest BtR (0.192 ± 0.008), followed by erratic swimmers (0.244 ± 0.027), and finally by floaters (0.273 ± 0.019). During the summer fish that swam immediately downward had the lowest BtR (0.275 ± 0.006), followed by erratic swimmers (0.329 ± 0.024), and finally by floaters (0.402 ± 0.023). Scores for fish that were consumed at release were lowest in the fall (0.255 ± 0.021) and highest in the summer (0.312 ± 0.034).

Over the course of the experiment 10.4% of the subjects were consumed by predators at release, with the fall samples showing highest proportion at 14.6% and the lowest during the summer at 2.6% (Fig. 2). During the fall most of the observed predation occurred at the 60 m site, whereas during the summer there was no difference by sampling depth (Fig. 2). Predation frequency was significantly different by depth ($F_{1,418} = 5.05$, $p = 0.03$), by season ($F_{1,418} = 5.845$, $p = 0.02$), and had a significant interaction ($F_{1,418} = 13.22$, $p < 0.001$). There was no significant logistic relationship between BtR score and predation for either the fall or summer sampling season. Predation rate increased as BtR increased from 0.0 to ~0.4 and appears to conform to the hypothesized logistic relationship for that range of impairment. However, there was no predation of fish with a BtR above 0.5. A total of 25 fish had BtR scores above 0.5, of which only 4 fish were able to swim downward while the rest floated at the surface. Of these 25 fish, 18 were captured during the summer sampling period when predation rate was lowest and impairment was highest. The remaining 7 fish that were captured in the fall all floated at release. Of the prey subjects 52% floated prior to consumption, 6% swam erratically, and 42% had begun to swim downward.

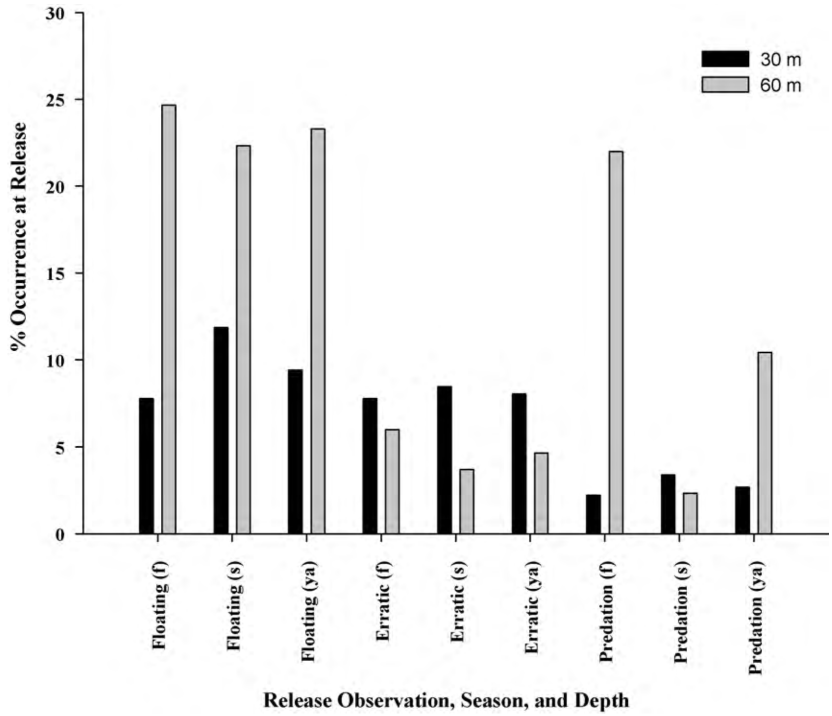

Fig. 2. *Lutjanus campechanus.* Percent occurrence of floating, erratic swimming, and predation after release by depth treatment and season. f = fall, s = summer, ya = project average.

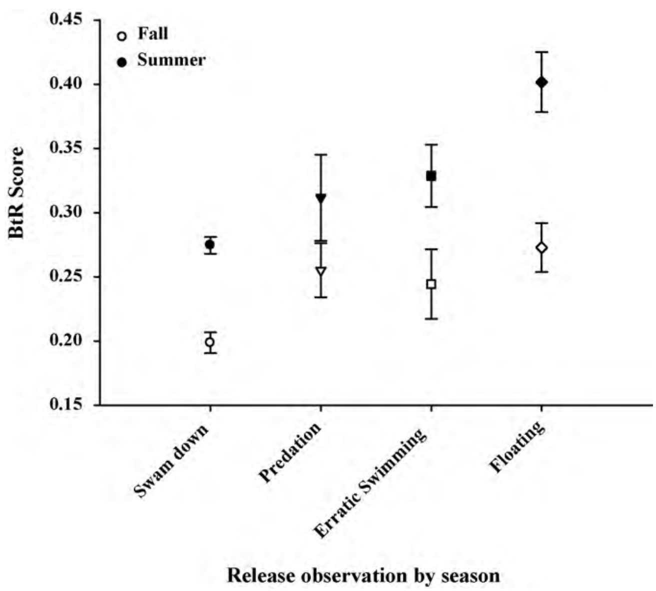

Fig. 3. *Lutjanus campechanus.* Mean BtR scores ± 1 se, by release activity: swam down, predation, floating, and erratic swimming.

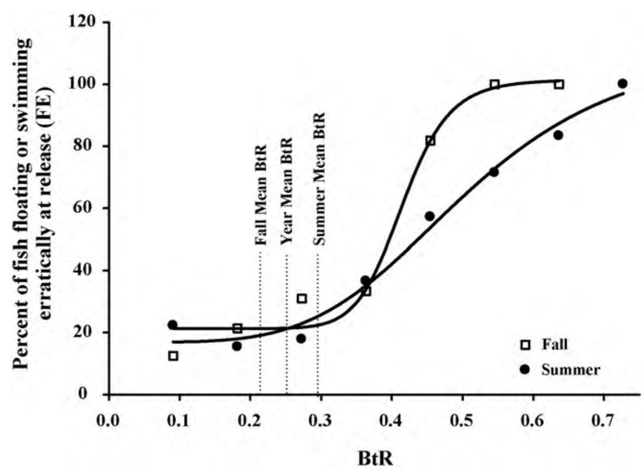

Fig. 4. *Lutjanus campechanus.* Logistic relationship ($y = a/(1 + (x/x_0)^b)$) between BtR score and % release mortality when discard activities of floating and erratic swimming (FE) are considered mortalities, during summer and fall sampling.

3.3. Release activities as proxies of mortality

Mortality, as estimated by the FE, FP, and FEP proxies, was significantly related to BtR in a sigmoidal fashion, as was hypothesized (regression coefficients listed in Appendix A). Percent release mortality estimated using FE showed significant logistic relationships with BtR for both seasons (fall, $F_{3,6} = 51.83$, $p = 0.0044$, $r^2 = 0.98$; summer, $F_{3,7} = 95.1$, $p = 0.0004$, $r^2 = 0.98$). Using the FE proxy and the two seasonal mean estimates of BtR and the coefficients for the two logistic regressions (fall and summer), estimates of percent release mortality ranged from 21.3 to 25.8, and was highest for the summer sampling period (Table 2 and Fig. 4). In the absence of predation (FE) the predicted release mortality was higher during the summer than for the fall. As BtR scores increased above 0.36, all FE logistic regressions showed increasing estimates of immediate percent release mortality (Table 2 and Fig. 4).

Percent mortality estimated using FP showed significant logistic relationships to BtR for both seasons (fall, $F_{3,6} = 37.67$, $p = 0.007$, $r^2 = 0.97$; summer, $F_{3,7} = 108.32$, $p = 0.0003$, $r^2 = 0.98$). The FP percent release mortality estimates ranged from 16.7 to 22.6 (Table 2 and Fig. 5), with the fall sampling showing the highest estimate. The FP release mortality estimates were higher than from the FE estimates for the fall samples throughout all levels of BtR, and were particularly accentuated above BtR > 0.36 (Table 2 and Fig. 5). High rates of predation during the fall contributed more mortality for that time period than did the erratic swimming proxy. The FP mortality estimate for the summer samples did

Table 2
Lutjanus campechanus. Predicted release mortality under various scenarios. Upper estimates are calculated with the positive bound of the BtR (1 se) and lower estimates calculated with the lower bound of the BtR estimates (1 se).

	Fall			Summer			Fall/high BtR		
	30 m	60 m	Avg	30 m	60 m	Avg	30 m	60 m	Avg
BtR	0.18	0.24	0.22	0.27	0.30	0.29	0.27	0.30	0.29
SD	0.09	0.13	0.12	0.11	0.12	0.12	0.11	0.12	0.12
Fl	15.33	15.49	15.39	16.37	17.52	17.06	15.90	16.98	16.50
FE	21.27	21.36	21.30	22.69	25.75	24.63	21.64	22.61	22.16
FP	22.55	22.59	22.57	16.73	17.87	17.41	22.71	23.12	22.93
FEP	26.80	26.86	26.82	23.15	26.22	25.10	27.06	27.81	27.46

Fl = floating; FE = floating + erratic swimming; FP = floating + predation; FEP = floating + erratic swimming + predation.

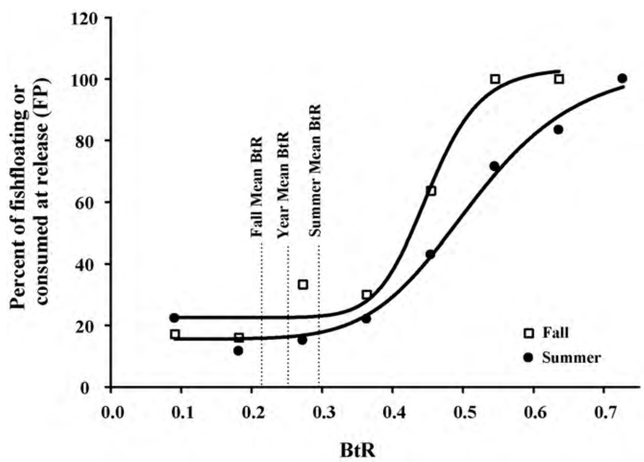

Fig. 5. *Lutjanus campechanus.* Logistic relationship ($y = a/(1 + (x/x_0)^b)$) between BtR score and % release mortality using floating and predation (FP) are considered mortalities, during summer and fall sampling.

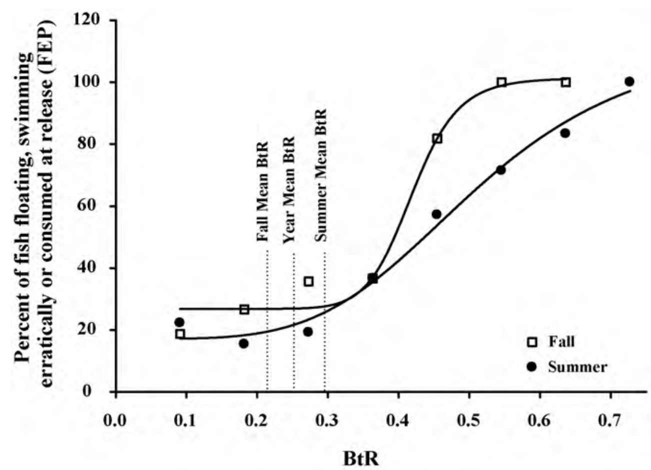

Fig. 6. *Lutjanus campechanus.* Logistic relationship ($y = a/(1 + (x/x_0)^b)$) between BtR score and % release mortality when floating and erratic swimming and predation (FEP) are considered mortalities, during summer and fall sampling.

not increase release mortality above FE estimates at any level of BtR.

Percent mortality estimated using FEP showed significant logistic relationships for both seasons (fall, $F_{3,6} = 52.45$, $p = 0.004$, $r^2 = 0.98$; summer, $F_{3,7} = 107.75$, $p = 0.0003$, $r^2 = 0.98$). Using the FEP proxy increased release mortality estimates over the previous two combinations analyzed (Table 2 and Fig. 6). The fall FEP logistic curve resulted in the highest percent release mortality estimates (ranging from 23.2% to 26.8%) when predation was at a maximum. The release mortality estimates were particularly accentuated with BtR > 0.36.

To evaluate a potential worst-case possibility, the high predation logistic regression coefficients were combined with the high BtR estimated during the summer (Table 2). The estimates from this scenario produced the highest level of estimated immediate release mortality of ~27% for the FP and FEP logistic regressions.

4. Discussion

4.1. BtR impairment and mortality

Impairment scaling is a simple and effective method to predict both immediate (in this study) and delayed mortality in the red snapper fishery (Diamond and Campbell, 2009). Similar to laboratory results (Campbell et al., 2010), impairment of red snapper associated with CAR fishing showed positive relationships between BtR and both capture depth and water temperature. Increasing depth of capture has also been shown to be negatively related to submergence ability of three species of rock fish (*Sebastes* spp.) (Hannah et al., 2008). Recaptured fish showed significantly lower impairment than non-recaptured fish as measured by BtR.

There were significant logistic relationships between BtR score and estimated immediate mortality as measured by combinations of release proxies and predation (FE, FP, and FEP). The relationship between impairment and immediate release mortality was primarily associated with the high frequency of floating following release. Percent release mortality estimated from logistic regression coefficients increased with increasing impairment regardless of proxy combination. Logistic curves had inflection points ranging between 0.3 and 0.4 BtR. Above inflection fish experienced high mortality regardless of season. In all treatments, however, mean BtR was lower than the inflection point resulting in release mortality estimates ranging from 20% to 28%.

Seasonal differences in water temperature appear to be a significant factor in estimated immediate release mortality. When release activity proxies are the sole considerations (Fl or FE), the highest predicted percent mortalities were associated with summer sampling efforts, during which time the frequency of floating increased substantially particularly from the deep site. Recaptured fish show significantly lower BtR scores than non-recaptured fish inferring that during periods of time when fish experience elevated impairment fewer tag returns would be expected. Fewer fish were recaptured during the summer (5) when impairment was highest than during the fall (17) when impairment was lowest, however sample sizes of recaptures are low. Thermal stress and barotrauma are both cited as important causes of impairment and mortality for many species of fish including red snapper (Davis et al., 2001; Davis, 2002; Diamond and Campbell, 2009; Campbell et al., 2010). Recreational red snapper regulations limiting fishing to summer months are mismatched with the physiological capability of the species to cope with CAR fishing stress and is most likely associated with increased impairment from elevated water temperature.

During the fall the frequency of floating was lower than during the summer, but predation was substantially higher, implying that one source of mortality (floating) was replaced by another (predation) during that time. Correlation between fish impairment and predation mortality has been established in laboratory experiments (Ryer, 2002; Ryer et al., 2004), and for red snapper specifically, impairment has been linked to decreased ability to react to and swim away from a simulated predator (Campbell et al., 2010). In this study predation mortality did not relate to BtR as hypothesized, instead, at the highest levels of impairment predation ceased completely. This trend could be the result of: (1) small sample size at the highest levels of impairment, (2) highly impaired fish being released in the absence of predators, or (3) a combination of both. Predation rate either peaks seasonally or there is high spatio-temporal variation, both of which convolute assessment of the contribution of predation to release mortality. In this study the lowest level of predation happened to coincide with the highest levels of impairment (summer) and vice versa (fall). If a scenario occurs that combines increased impairment of released fish with high predation, then the hypothesized logistic response might result. To better isolate the relationship between increasing impairment and predation, larger sample sizes are needed as well as better control of experimental conditions, both of which may be unrealistic to expect in the field.

4.2. Management implications

Immediate percent-mortality estimated from the FE mortality proxy ranged from 20% to 25%, and the FEP proxy estimated 23–28%. Gulf of Mexico red snapper stock assessments have historically used a release mortality estimate of 20% and currently use 15% for the eastern stock and 40% for the western stock (Schirripa and Legault, 1999; SEDAR 7, 2004). Excluding erratic swimmers, percent mortality estimated here did not fall as low as the 15% estimate, and furthermore is lower than 20% only when conditions include shallow water and low predation rates (summer). Observations of discarded fish by the Texas headboat fleet in 1999 found that 15.2% of the subjects floated away, and 22.8% swam erratically upon discard (Dorf, 2003), whereas this study showed 19.3% and 5.6% respectively. A three-year study of the Texas headboat fleet estimated that between 8% and 17% of fish either floated or swam erratically upon release (port and year), and the proportion increased with increasing sampling depth (Kleisner personal communication).

Recreational red snapper fishing is currently confined to summer months (June 5–August 5), therefore fall estimates do not reflect the impairment occurring when CAR fishing will maximally impact the fishery. Combining summer impairment estimates with coefficients from the fall logistic regressions (high predation rate) inflated estimated release mortality (FP = 22.9%, FEP = 27.5%). Not knowing the cause of low predation experienced during the summer sampling cruise does not preclude that high predation rates could be experienced during summer months. More information on the extremes of impairment and predation rate over a broad range of environmental and fishing conditions is needed.

The proxies measured here are by definition only substitutes of mortality and in this case are still measured within 1 min. Other studies have shown delayed mortality rates (days) in the recreational fishery as high as 64% (Diamond and Campbell, 2009), and immediate mortality estimates from the commercial fishery as high as 69% (Nieland et al., 2007). Discarded fish that do not immediately float, swim erratically, or are preyed upon may perish days later from extensive internal damage from barotrauma, starvation, hooking trauma, or predation (Rummer and Bennett, 2005). There is a good probability that mortality continues to increase several days after release. Lack of tag returns in this study could also be indicative of low survival particularly for fish showing elevated impairment. The immediate release mortality estimates generated in this investigation are likely underestimates because of this delayed mortality component, particularly for depths greater than 30 m and with sparse information on spatio-temporal variation associated with predation.

4.3. Conclusions

The BtR methodology is easily employed during discard observation, is useful in scaling impairment, and provide reasonable estimates of release mortality. Adding this component into a discard observer program would enhance and broaden data with little cost in terms of effort by the observer and stress to the fish. The effect of capture stress on individuals and fished populations is not well understood and sources of uncertainty still need more clarification. While individual behavior at release can be predicted by the level of impairment, behavior of predators in relation to impaired prey is unclear. Estimates of predator density, interest in feeding, visitation and attraction of predators to release sites will all need significant attention to help clarify the contribution of predation to release mortality. The next step is figuring out how to make use of this information and clarifying how to combine immediate and delayed estimates into a single release mortality estimate.

Acknowledgements

This work was funded by National Marine Fisheries Service (NOAA)—cooperative research program grant # NA04NMF4330076. We thank the following people and organizations for their contributions: Michael Davis for technical advice on impairment scaling, Daisy Duursma, Tiffany Hopper, Steve Qualia, Todd Neahr, and Jace Tunnell for their assistance in collections; G&S Marine, Mike Nugent of Wrecklamation Charters, and Capt. Brad Barwise of Waterworld Charters for logistics, support and assistance in collections and general knowledge of red snapper.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.fishres.2010.07.004.

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