Estimating discard mortality of black sea bass (*Centropristis striata*) and other reef fish in North Carolina using a tag-return approach

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Abstract

Mortality of discarded fish, while difficult to quantify, may contribute substantially to the overall rate of fishing mortality for deepwater (> ~ 20 m) reef species. Observations of fish behavior upon release may not reflect rates of delayed mortality because of predation, hook trauma, or barotrauma. We estimated survival rate by release condition using tag recapture data for five reef fish species: black sea bass, red porgy, white grunt, gray triggerfish, and vermilion snapper; survival was estimated as a ratio of returns in a compromised condition relative to return rates of fish released in the best condition. Fish were captured with traps and hook and line from a narrow depth range (29 - 37 m) off the coast of North Carolina, marked with internal anchor tags, and observed for condition upon release. Estimates of discard mortality were obtained by applying condition-specific survival rates (estimated from tag returns) to numbers in each category observed in independent (non-tagging) commercial and recreational fishing operations. Generally, survival decreased with increasingly compromised release conditions across species. Return rates from SCUBA- and boatside-releases did not differ, indicating that predation while swimming from the surface to bottom was negligible for black sea bass in the best condition. The survival rate of black sea bass with visible signs of barotrauma was ~100% and higher than those with hook trauma (non-jaw hooking). For hook and line and trapping, discard mortality rates were much lower than the assumed 15% value currently used in assessments (hook and line average = 4.3 %; trap average = 0.7 %). Rates of discard mortality were highest at deeper depths but the relationship between discard mortality percentage and depth for each gear was not significant at the depths over which commercial and recreational data were collected. Estimated rates of discard mortality for reef species will become more accurate with further refinements to survival estimates of fish in the best release condition.

Introduction

The quantity and disposition of discarded fishes is a ubiquitous issue in fisheries worldwide (Alverson et al. 1994). Quantifying the disposition of discarded fish is an important task for fisheries managers because it is often a source of uncertainty in estimating the overall rate of fishing mortality. In many fisheries, there is an unknown rate of mortality for individuals that are caught with fishing gear and then released (Davis 2002).

The South Atlantic Fishery Management Council (SAFMC) uses size limits to manage reef fishes in the U.S. South Atlantic. A high percentage of reef fish captured in North Carolina are undersized (Rudershausen et al. 2007). Managers assume that the benefits of current size limits for black sea bass (*Centropristis striata*), red porgy (*Pagrus pagrus*), vermilion snapper (*Rhomboplites aurorubens*), and other size managed species offset rates of discard mortality over the depths these fishes are captured. For these species, methods need to be developed to accurately measure rates of discard mortality of sub-legal fish. This would help determine the utility of using minimum size limits (Wilson and Burns 1996).

Reef fishes in the U.S. South Atlantic may not survive catch and release because they have physoclistous swim bladders that often rupture during rapid ascent when retrieved; they may not be able to return to the bottom or may have fatal injuries even if they do return to the bottom (Rummer and Bennett 2005). In addition to the effects of barotraumas, released reef fish may die from gear trauma, stress, predation, or a combination of these factors (Davis 2002; St. John and Syers 2005; Rummer 2007). Depth of capture, water temperature, the presence of predators, retrieval rate, hook type, hooking location, time on deck, and venting are factors that determine whether fish with physoclistous swim bladders survive catch and release (Rummer 2007).

Mortality proxies (such as obvious barotraumas, floating, or deep hooking) have been used to infer mortality for reef fishes (Patterson et al. 2000; Rudershausen et al. 2007). However, the condition and behavior of reef fish immediately upon release may not reflect rates of delayed mortality. A recent study found that immediate mortality estimates from proxies were much lower than estimates of delayed mortality using location-specific hooking mortality rates and assuming fish with obvious signs of barotrauma die (Rudershausen et al. 2007); however, this latter assumption has not been tested adequately in reef fishes. Caging studies have been used to estimate discard mortality but may bias mortality estimates because of unmeasured interaction of fish in cages, elimination of predation, pressure effects from raising and lowering cages on multiple occasions, and questions about whether a fish's caged environment approximates what it would experience outside of it (Davis 2002; Guccione 2005; Pollock and Pine 2007). Previous tagging studies to estimate delayed discard mortality (Wilson and Burns 1996; McGovern et al. 2005) have combined data across a wide range of depths, which does not control for declining fishing effort (and thus tag returns) with increasing distance from shore. Methods need to be developed to accurately determine rates of discard mortality of reef fishes inhabiting deep waters (> 20 m) off the southeastern United States.

Tagging methods have been used to estimate the delayed effects of catch and release fishing (Pollock and Pine 2007). Recently, a unique tagging method was used to estimate the survival of shallow water sharks after release (Hueter et al. 2006). Our objective was to apply this approach to estimate rates of post-release survival (and mortality) of reef fish species captured in Onslow Bay, NC. These species include: black sea bass, red porgy, vermilion snapper, white grunt (*Haemulon plumieri*), and gray triggerfish (*Balistes capriscus*).

Here we estimate discard mortality of reef fishes using Hueter et al's (2006) two-step approach. In the first step, fish were tagged and assigned a release condition based on their behavior and external signs of trauma. In the second step, tag return data were used to estimate the survival of fish in increasingly more compromised conditions relative to conspecifics in the best release condition. The survival-by-release condition data were then used to estimate discard mortality from independent commercial and recreational fishing operations.

Methods

Data collection

The depth range over which to capture, mark, and release fish was carefully considered. We selected a range of 29 - 37 m in Onslow Bay, NC, which encompasses numerous 'live-bottom' habitats visited by commercial, recreational, and charter boat fishermen. This depth range balanced remaining relatively close to shore (to maximize the tag return rate through greater near-shore effort by fishermen) but fishing waters deep enough where discarded reef fish exhibit a wide range of discard conditions (see below). Moreover, the depth range that we selected spans a sufficiently narrow inshore-offshore distance in Onslow Bay (~15 km) where tag return rates among fish in various release categories (and therefore rates of relative discard mortality) can assumed to be related to fish condition rather than declining fishing effort (thus declining rates of tag returns) with increasing distance offshore.

We elected to tag five species important to the commercial and recreational reef fisheries in the U.S. South Atlantic: black sea bass, red porgy, vermilion snapper, gray triggerfish, and white grunt. Black sea bass, red porgy, and vermilion snapper are managed with minimum size limits while the other two species are not. These five species have historically been captured together in deepwater reef patches off the coast of North Carolina (Rudershausen et al. 2008a but are caught shallow enough that some released individuals appear to survive (Rudershausen et al. 2007)

Field sampling with researcher attendance on trips to capture, tag, and recapture marked fish occurred from 23 August 2007 to 13 August 2010 on commercial, headboat, and research vessels. Sea surface temperatures over these days sampling ranged from 11 to 29°C. Tag return data from fishermen were obtained from August 2007 to August 2010.

Fish were captured with three gears commonly used in commercial, recreational, and headboat fisheries for reef species: electric hook and line, manual hook and line, and traps. Hook and line sampling used rods, and manual and electric reels. Reels were spooled with 59 kg Spectrabraid® line. Terminal tackle for hook and line fishing consisted of a high-low bottom rig made from 91 kg monofilament that connected a 540 g lead sinker and two 'J' hooks ranging from 2/0 to 5/0 in size. These hook sizes and style typify those used for reef fishing in the U.S. South Atlantic. Hooks were baited with cut squid or cut fish. Each rod-caught fish (both shallow and deep-hooked) was removed from the hook with a de-hooking tool.

Traps were constructed of 12-gauge vinyl-coated square mesh. Two trap mesh sizes were used to catch reef fish; one trap type had 38.1 mm mesh on all six sides, and the other trap type had 38.1 mm mesh on five sides of the trap with a 50.8 mm back panel. The smaller mesh trap was used to maximize the capture rate of small (<~250 mm) black sea bass. External dimensions of each trap were 61 cm long and wide, and 56 cm high. Each trap had a single chamber (i.e., no upper vs. lower parlors), two funnel entrances on opposite sides, and a bait well extending the full depth of the trap. Two 16 mm rebar frames were attached to the bottom of each trap. Traps were baited with frozen Atlantic menhaden *Brevoortia tyrannus*. Trap soak times ranged from one to 15 hours, typical of the commercial black sea bass trap fishery in the U.S. South Atlantic.

For each tagged fish we recorded total length (mm), hook location (for fish captured with hook and line), presence/absence of visible barotrauma, tag number, and release condition (see below). Barotrauma included any of the following symptoms: stomach protruding into esophageal cavity or out mouth (stomach eversion), intestine protruding out the anus (intestinal protrusion), or exophthalmia. Deck time among fish tagged and released in this study varied between 30 and 90 seconds, but was shorter or longer in some instances. This time was not recorded due to the high number of fish that were processed. However, we believe that this variable deck time is representative of the fishery. Deck time in the reef fishery in the U.S. South Atlantic ranges from seconds to minutes (pers. obs.). The variation in deck time depends on the inclination fishermen to cease angling long enough to measure fish that are close to the minimum size (pers. obs.). For the black sea bass trap fishery, the relationship between deck time (air exposure) and observed release condition was found to be non-significant (Rudershausen et al. 2008b).

Fish were tagged after being measured and observed for hook trauma (hooked fish) and/or barotrauma (trapped fish and hooked fish). Internal anchor tags (Floy® FM-89SL) were used to mark fish ≥ 150 mm total length. For size-managed species, both legal and sub-legal fish were tagged in order to maximize the number of fish that were released and the subsequent rate of returns. The message on each tag included a toll-free phone number in two places (streamer and disc), the tag number on three places (two on the streamer and one on the disc), the reward amount ($5) on the streamer, and a message to 'cut tag.' All recaptured fish (regardless of size) were released and recorded for release condition on research trips.

After each fish was tagged, it was released and assigned one of six conditions based on behavior. These release conditions were modified after Patterson et al. (2000): 1) alive, no visible hook- or barotrauma, oriented toward the bottom, and swam down vigorously; 2a) alive, with hook trauma, oriented toward the bottom, and swam down; 2b) alive, with barotrauma, oriented toward the bottom, and swam down; 2c) alive, with hook- and barotrauma, oriented toward the bottom, and swam down; 3) alive but floated at the surface, regardless of trauma; and 4) presumed dead. Fish in release condition 1 were separated from those in conditions 2a, 2b, and 2c because it is assumed that barotrauma (Wilson and Burns 1996; Coleman et al. 2000; McGovern et al. 2005; Rudershausen et al. 2007; Rummer 2007; Campbell et al. 2010) and hook trauma (Bugley and Shepherd 1991) compromises the ability of reef fish to survive release. The inability of fish in condition 3 to orient themselves or submerge has been used as a proxy for mortality (Davis and Ottmar 2006; Rudershausen et al. 2007, Hannah et al. 2008).

Tagged fish were recaptured by researchers and recreational and commercial fishermen. When reporting a tagged fish, a fisher was questioned for the date and location of recapture. The majority of tags were returned in batches so information about location and date of recapture of individual fish could not be obtained.

Data analysis

To compute rates of discard mortality, we used data from tag returns provided from research trips as well as the commercial, recreational, and charter boat sectors of the reef fishery. Recapture information was used when the recapture date was at least three days after the date of tagging. The relative long-term survival rate (S) of fish in condition 2a, 2b, 2c, 3, and 4 respectively, compared to fish in condition 1 was calculated as;

$$S = \frac{C_n / N_n}{C_1 / N_1}$$

where C_n/N_n is the ratio of returns of fish in condition n to the number of fish tagged in that condition n (2a, 2b, 2c, 3, or 4) and C_1/N_1 is the ratio of returns of fish in condition 1 to the number of fish tagged in condition 1; the tagging model assumes that fish in the best condition survive as well as those never caught (Hueter et al. 2006). Calculating relative rates of discard mortality with the model also assumes that fish among different release conditions have the same survival (after an initial period (days) of recovery), catchability, and tag reporting rate (Heuter et al. 2006). We estimated survival and 95% confidence intervals using relative risk analysis (SAS Institute, JMP v.7.0 2007) described by Hueter et al. (2006). For fish recaptured more than once, we used only the first recapture to compute relative survival.

We conducted additional tests with black sea bass return data due to the high numbers of this species that were tagged and the high percentage returned. It has been suggested that release condition at the surface, such as swimming behavior, may serve as a proxy for mortality for released reef fishes (Patterson et al. 2000; Dorf 2003; Campbell et al. 2010). To determine the efficacy of this mortality proxy we divided recreationally sub-legal (< 305 mm total length) black sea bass in two groups: those that swam (conditions 1, 2a, 2b, and 2c) and those that floated (conditions 3 and 4). We then used a chi-square contingency test to determine whether the computed ratio of living-to-dying fish in these two groups (based on computations from the tagging model) differed from the assumption that swimming fish would uniformly live and fish floating would uniformly die.

Internal anchor tags may vent reef fish and lead to higher survival as a result of fish being able to swim back to the bottom. There might also be higher survival rates within a category, which would bias application of the same condition score when fish were not vented. We performed two different tests on black sea bass to evaluate these possibilities. First, we compared number by release condition for 31 tagged and 31 untagged fish that were released simultaneously. A chi-square contingency test was used to compare frequencies of floating and swimming between tagged and untagged fish. Second, we examined whether survival estimates of barotraumitized (condition 2b) individuals differed between first-released fish (vented) and second-released fish (non-vented because already tagged); the denominator, the return rate of condition 1 fish, was specific to each category (vented vs. non-vented). This analysis was conducted with condition 2b black sea bass because this was the only compromised release group with sufficient sample sizes of fish that were recaptured twice. Both analyses to evaluate the effect of venting were conducted by combining data across both size groups of black sea bass ($\geq$ 305 mm and < 305 mm total length).

We determined if black sea bass return data could be combined across gear types used to initially capture black sea bass (traps and hook and line). To ensure effort to recapture tagged fish was similar for tagged fish caught and released from both gear types, we restricted the analysis to a spatial area where the cooperating fisher released hook and line and trap caught fish; additionally, we only used fish caught and tagged from small mesh traps to ensure that similar size distributions of fish were available for recapture. A 2 x 2 contingency table of condition 1 black sea bass was used to compare frequencies of recaptures in both gear types; the two columns were the number recaptured and the number not recaptured and the two rows were the number tagged and released after hook and line capture (n = 10 and 31 in the two columns) and the number tagged and released after trap capture (n = 313 and 1183 in the two columns). The result of this contingency test was non-significant ($\chi^2 = 0.29$; p = 0.591); hook caught and trap caught condition 1 black sea bass had equal return rates. This result justified combining data across gear types.

We also wanted to determine whether the return rate of condition 1 black sea bass depended on fish size. For this analysis we restricted data on released and recaptured black sea bass to those days when the commercial cooperator was using trap mesh sizes smaller than the legal minimum in order to minimize any size selectivity that would bias recapture towards larger fish. For this contingency test the two columns were the number recaptured and not recaptured. The two rows were the number < 305 mm total length (n = 79 and 1063 in the two columns) and ≥ 305 mm total length (n = 38 and 311 in the two columns). We chose this size cutoff (the minimum legal size for the recreational fishery in the U.S. South Atlantic) because a far greater percentage of black sea bass are discarded from hook and line than from trapping in this region (Rudershausen et al. 2008b; NOAA 2010). This result was significant ($\chi^2 = 5.83$, $p = 0.016$), so we developed separate discard mortality estimates for recreationally legal and sub-legal black sea bass.

Finally, we sought to determine whether return rates of condition 1 black sea bass differed between fish released at the surface and the bottom. Such a difference in the return rate might indicate predation on newly released fish that must swim through the water column and a violation of the assumption that condition 1 fish survive as well as fish never caught. Condition 1 black sea bass were released at the surface while simultaneously placing a group of condition 1 black sea bass in a trap; fish that were placed in the trap boatside were then quickly released at the bottom by SCUBA divers who observed fish for a short period (~15 minutes) after releasing fish. The two columns for this contingency test were the number of condition 1 fish returned and not returned. The two rows were the number of fish released at the bottom by divers (n = 33 and 320 in the two columns) and at the surface (n = 37 and 281 in the two columns). This result was non-significant ($\chi^2 = 0.19$, $p = 0.662$), so the assumed survival rate (100%) of condition 1 black sea bass was not adjusted for predation mortality.

We estimated black sea bass discard mortality from 25 recreational and commercial fishing trips where this species was caught in Onslow Bay, NC; these trips were independent of the tagging study trips. During these trips, untagged fish were released and release conditions were assigned. These data sets were separated by user group, gear type, and average depth of capture. Two of the commercial data sets were collected with electric hook and line and nineteen with fish traps (with legal trap mesh dimensions) in waters from 11 to 29 m deep. Recreational data sets were collected from depths from 20 to 31 m and included two electric hook and line and two manual hook and line data sets (Rudershausen et al. 2008a). We did not use catch-and-release data from this tagging study to estimate discard mortality due to concerns about internal anchor tags venting fish and thus helping them return to the bottom. For each of the 25 data sets, we computed percent discard mortality by using data from average black sea bass survival by condition and weighting by numbers of fish released in each of the six conditions. The assumption of this approach is that survival estimates for each of the conditions estimated from tagging and recapturing fish in this study apply to other depths where fish are observed for release condition but not tagged. For each of the two gears (traps and hook and line), we investigated the relationship between percent discard mortality and depth using Spearman rank correlation.

Results

A total of 8,108 fish were tagged and 1,157 were returned at least once. For fish that were reported at least once, tag return rates by species ranged from a high of 22.5 % (black sea bass, both size groups combined) to a low of 2.0 % (vermilion snapper) (Table 1). A total of 1,026, 159, 25, 5, 2, 1, and 1 black sea bass were recaptured once, twice, three, four, five, six, and seven times. There were no tag returns (from any species) north of Cape Hatteras or south of Cape Fear; all black sea bass were recaptured in Onslow Bay. Maximum time at large for recaptured fish ranged from days to over two years for each of the five species tagged (Figure 1).

Survival percentages generally declined with less favorable release condition for each species (Table 1). Lower numbers of releases and recaptures for a particular species and release condition yielded wider confidence limits about survival estimates. For each species, fish that were released with barotrauma generally survived as well as those released without it. For each size group of black sea bass, fish with visible barotraumas (condition 2b) had a higher survival percentage than those with hook trauma (condition 2a) (Table 1).

Behavior (swimming vs. floating) has been used as a proxy for determining whether reef fish survive or die upon release. For black sea bass < 305 mm TL that were in conditions 1, 2a, 2b, and 2c, the assumed ratio of living:dying fish (100:0) was not significantly different than the ratio computed from the estimated survival rates (3186 out of 3236 fish in conditions 1, 2a, 2b, and 2c estimated to have survived when using a 100% survival rate for 2b fish) (using survival data from both size groups) ($\chi^2 = 0.77$; $p = 0.379$). For black sea bass in conditions 3 and 4, the assumed ratio of living:dying fish (0:100) was significantly different than the ratio computed as above (32 out of 220 fish in conditions 3 and 4 estimated to have survived) ($\chi^2 = 4.68$; $p = 0.030$).

Tagging released pressure inside black sea bass and a higher percentage of these fish were able to swim down compared to untagged fish in 31 paired trials between fish tagged and released and fish released without getting tagged ($\chi^2 = 8.71$; $p = 0.003$). This led to a higher percentage of fish in category 3 and 4 than observed in the remainder of the tagging study.

Across all sizes of black sea bass, the survival estimate of barotraumitized (condition 2b) fish was 104.8% after being vented (tagged) and recaptured the first time, and 100.2% after being recaptured a second time (77 out of 168 fish observed as condition 2b upon the second release were recaptured a second time, while 91 out of 199 fish observed as condition 1 upon the second release were recaptured a second time). Thus, venting did not appear to change the survival rate of fish in a compromised condition.

Most black sea bass were scored as condition 1 or 2b fish from the 25 data sets where fish were observed but not tagged; therefore, estimates of discard mortality were low. For hook and line data sets, estimates of discard mortality ranged from zero to 6.9 % (average = 4.3 %). For trapping data sets, estimates of discard mortality ranged from zero to 5.3% (average = 0.7%) (Figure 2; Table 2). For hook and line and traps, the highest values of discard mortality occurred at the greatest depths but the correlation between depth and percent discard mortality was not significant for each respective gear ($r = 0.185$; $p = 0.725$ and $r = 0.342$; $p = 0.152$). For common depths of capture (≥ 20 m), the average discard mortality from hook and line ($n = 6$) was greater than for traps ($n = 10$) (Mann-Whitney $U = 7.5$; $p = 0.009$).

Discussion

We had high tag return rates of black sea bass relative to each of the other four species that we tagged. The ability to capture high numbers of fish to apply this tagging model is important because studies of reef fishes typically have low rates of tag returns (< ~ 10 %) (Wilson and Burns 1996; McGovern et al. 2005). Our tag return rates (~22.5 %) were high for black sea bass and about average for the other four species (3.8 % for red porgy, 3.1 % for white grunt, 8.4 % for gray triggerfish, and 2.0 % for vermilion snapper) when compared to other reef fish marking studies that have tagged black sea bass (Moser and Shepherd 2009), red grouper *Epinephelus morio* and scamp *Mycteroperca phenax* (Wilson and Burns 1996), and gag *Mycteroperca microlepis* (McGovern et al. 2005). The high numbers of recaptured black sea bass in this study allowed us to develop relatively narrow confidence limits about estimates of survival for various release conditions and test the assumption that condition 1 black sea bass survive as well as those never caught. The fidelity of this species to reef patches where we first caught them contributed to the high return rate. Return rates of red porgy, white grunt, gray triggerfish, and vermilion snapper were too low to obtain estimates of survival with reasonably narrow confidence limits. For this reason, the rest of discussion focuses on black sea bass.

The rates of discard mortality that we computed from 25 applied data sets are all less than the assumed rate of 15% applied to the commercial and recreational fisheries for black sea bass in the U.S. South Atlantic. The rate of discard mortality we obtained from applying the discard mortality estimates via tagging to hook and line data sets (where fish were not tagged) is very close to that found for sub-legal (≤ 30 cm total length) hook and line-caught black sea bass over capture depths of 6-12 m in New England (2.3%) (Bugley and Shephard 1991). The two major assumptions of this analysis are that: (1) the fish released in each condition experienced no mortality associated with the fishery interaction and (2) survival estimates by release condition determined at the depths in this study are valid for other depths as well. While a similar approach was applied to estimate rates of discard mortality of two reef species (gag and greater amberjack) (McGovern et al. 2005), those estimates may have been biased if declining fishing effort in deeper waters contributed to diminishing rates of tag returns.

Future estimates of survival rates of reef fish will benefit from further investigating the credibility of the assumption that fish in condition 1 survive as well as those never caught. A portion of this study was devoted to accounting for predation (or lack thereof) on fish in condition 1. We determined that predation on released black sea bass does not appear to contribute to post-release mortality. While presumably the predation effect is minor, condition 1 black sea bass that were either released at the surface or temporarily observed by divers could have been more susceptible to predation as they recovered over hours or days from capture, tag insertion, and release. Predation may still be a significant source of mortality of released deepwater reef fish in the U.S. South Atlantic (Davis 2002) and may occur immediately after release or as fish attempt to return to the bottom. Predators we occasionally observed while fishing included greater amberjack (*Seriola dumerili*) and king mackerel (*Scomberomorus cavalla*). While most of the mark-recapture work was done over live-bottom habitat, we have observed that predators are more abundant over shipwrecks and artificial reefs in Onslow Bay.

Tagging condition 1 fish simultaneously at the bottom and surface would allow us to control for the effects of barotraumas and further investigate the credibility of the assumption that condition 1 fish survive as well as those never caught. Matthews and Reavis (1990) described an efficient underwater tagging approach applied to rockfishes (*Sebastes* spp.). In contrast to the more obvious gas accumulation in the swim bladder (which often forces the stomach out the mouth), reef fish can suffer non-observable barotraumas from accumulations of gas in blood and tissues (St. John 2003); such unobservable barotraumas may bias our estimates if condition 1 fish had < 100% survival. Tagging fish at the bottom would help determine if such a bias exists.

Black sea bass were tagged near the greatest depths these fish are commonly captured in waters off North Carolina (Rudershausen et al 2007; Rudershausen et al 2008a; Rudershausen et al. 2008b; Collier and Stewart 2010; pers. obs.). Thus, survival rates by condition might be lower in this study compared to if we had tagged fish shallower waters. For example, the survival rates of >305 mm black sea bass released in the 2b condition might have been closer to

100% in shallow waters. Even if this positive bias in mortality exists, our estimates are still much lower than the assumed 15%.

Rates of discard mortality depend on the fishing gear and depth range over which fish are captured (Davis 2002). When applied to independent fishery data sets, overall discard mortality of black sea bass was highest for hook and line over similar depths. There was a positive trend between discard mortality and depth but the relationship was not significant for either gear. Previous work investigating depth-related rates of discard mortality in this species (Collins et al. 1999) and other reef fishes (e.g., Collins 1999; St. John and Syers 2005) has found a significant effect of depth likely because their work extended to deeper depths than those examined here. More data sets from deeper waters would have led to a significant relationship since there would have been more fish released in conditions 3 and 4. Thus, the discard mortality rates presented on Figure 2 for black sea bass should only be applied over those depths. Black sea bass are most commonly captured over shallower depths in the commercial trap fishery in North Carolina (Rudershausen et al. 2007; Rudershausen et al. 2008b; Collier and Stewart 2010), and roughly similar depths in the commercial hook and line fishery (Collier and Stewart 2010). No survey tracks depths of capture for recreationally caught black sea bass in North Carolina, but these depths appear to be similar or less than where we conducted our tagging for our study (pers. obs.).

The accuracy of our tagging estimates relies on the assumption that reef fish in condition 1 survived at rates equal to those that were never caught. A lower survival than the assumed 100% for fish released in condition 1 would mean that the current estimates are too high. Hueter et al. (2006) believed that their tagging model was not appropriate for estimating absolute post-release survival of deepwater reef species that have physoclistous swim bladders. However, we felt we were able to use the Hueter et al. (2006) model because the depth range for this study was not too deep where all barotraumas effects are lethal (Collins et al. 1999). Our estimates of percent survival by condition of black sea bass should be viewed as minimums because some fish in the best condition may have died from jaw-hook- or barotrauma. For another reef species, red snapper (*Lutjanus campechanus*), fish with unobservable internal organ damage did not always have visible barotraumas (Rummer 2007). Similarly, we can not rule out that some black sea bass in condition 1 could have had severe internal damage that caused delayed mortality; however, this appears unlikely given return rates of condition 1 and 2b fish that are near the high end of mark recapture studies for reef fishes.

The accuracy of our discard mortality estimates also relies on correctly assigning post-release conditions. It is clear that we did not assign correct post-release conditions in all cases. There were some fish in condition 4 (presumed dead) that were not dead, leading to overestimates of survival in this category. The subjectivity in assigning a release condition to a reef fish based on its behavior can substantially affect estimates of discard mortality. We modified the original Patterson et al. (2000) descriptions of post-release conditions; they separated non-traumatized fish that swam down quickly from those that swam down slowly. We chose to combine these groups based on the subjectivity of identifying swimming speed.

Swimming behavior and submergence success after release and other conditions (e.g., barotrauma, hook trauma, bleeding) have been used as proxies of survival/mortality in discard mortality studies of reef fishes (Rudershausen et al. 2007; Hannah et al. 2008; Rudershausen et al. 2008b). More favorable release conditions of black sea bass in this study paralleled greater rates of survival. The subjective visual assessment of reef fish condition may be the best predictor of survival (Sumpton et al. 2010). Hannah et al. (2008) believed for fish with physoclistous swim bladders that the ability to submerge after release may be a proxy for post-release survival. Our results agree with this assertion; recreationally sub-legal black sea bass that swam down (combined conditions 1, 2a, 2b, and 2c) were computed to have survived almost always. While some individuals can swim back to the bottom after rupturing their swim bladders, the interval between swim bladder rupture and healing is a time span over which a fish's chance of survival may be compromised by other factors (Burns et al. 2002). This may be less of a problem for near-bottom dwelling serranids and more of an issue for vermilion snapper because the latter taxa is often some distance off the bottom (Burns et al. 2002). This may have contributed to lower return percentage of vermilion snapper than other species we tagged.

There was a significant difference between assumed and computed ratios of living:dying fish for sub-legal black sea bass that did not swim down after release. However, the mis-identification (survival) of presumably dead fish and delayed swimming of briefly floating fish contributed to this result. Despite the difference between observed and expected ratios of living to dying black sea bass in conditions 3 and 4, we believe that floating is a good mortality proxy.

In modeling rates of discard mortality, it has been assumed that reef fish with obvious barotraumas die after release (Rudershausen et al. 2007). However, over the depths that we tagged, as well as shallower waters, the assumption that visible barotrauma can be used as a proxy for mortality for fish after they are released is not valid; this is consistent with observations in red snapper (Gitschlag and Renaud 1994). Although barotrauma in reef fishes has been referred to as a 'catastrophic' condition (Rummer and Bennett 2005), the majority of black sea bass with obvious barotrauma survived the catch and release process. There are a number of non-obvious forms of barotrauma that fishes may sustain when reeled from depth (Feathers and Knable 1983: St. John 2003; Morrissey et al. 2005; Rummer and Bennett 2005; St.

John and Syers 2005) that may contribute to mortality even though they cannot be observed (Rummer 2007); however, based on our results these do not seem to lead to high mortality in black sea bass at the depths of our study.

In contrast with barotrauma, results from hook traumatized fish show that the majority of these individuals die after release. This is consistent with observations of the effects of hook trauma (non-jaw hooking) across a range of species (e.g., Bugley and Shepherd 1991; Diodati and Richards 1996; St. John and Syers 2005; Reeves and Bruesewitz 2007; Alós 2008). The high mortality rate appears to be due to hook damage to well-perfused vital organs (e.g., stomach, gills), which increases the rate of mortality relative to peripheral areas such as the jaw (Diodati and Richards 1996).

We used internal anchor tags to mark fish. The tagging method may have an effect similar to venting in that it released gases from the abdomen. Venting is not a required or widely practiced technique among North Carolina commercial and recreational reef fishermen. In a separate study, the benefits of venting black sea bass and vermilion snapper were found to increase with depth, and increase survival rates compared to not venting (deflating) fish (Collins et al. 1999); the depth ranges over which venting increased survival in that study were 20-23 m, 29-35 m (similar to our study), and 43-55 m. In contrast, two recent analyses of venting concluded that it did not increase survival across a wide range of fisheries (Wilde 2009; Sumpton et al. 2010). Our data indicate that venting (via tagging) reduces the percentage of floaters over the depths that we marked fish. The greater ratio of swimming:floating fish in the vented (tagged) group provides justification for estimating discard mortality rates from 25 separate data sets (where fish were not tagged) rather than from the tagging data set itself. However, the benefits of venting versus stress of increased deck time, handling, and needle injury to small reef fish, should be considered before managers condone this practice for the black sea bass recreational or commercial fisheries. This is particularly true for our study depths given the small absolute number of floating fish.

Reef fishes in the U.S. South Atlantic are susceptible to multiple factors that may cause discard mortality. In this study we investigated the hook trauma, barotrauma, and predation on rates on discard mortality. There are other factors that influence rates of discard mortality that warrant investigation. These include water temperature, hook type, dehooking method, and deck time (air exposure) before fish are released. Our study was conducted throughout the year and water temperatures that are common to the fishery. The other factors listed were kept constant within each gear and user group type.

Impact and Benefits

The vast majority of black sea bass from this study were released in conditions (1 and 2b) where rates of survival were estimated to be very high. If the recreational and commercial fishery throughout U.S. South Atlantic operates in similar depths to those in North Carolina then our results suggest that the assumed rate of 15% discard mortality for black sea bass is too high. Our analysis includes comprehensive observer data on the number and disposition of discards over a variety of fishing depths and for the two main gear types used to catch black sea bass in the U.S. South Atlantic.

The commercial fishery in the U.S. South Atlantic uses traps that are highly selective for legal black sea bass (Rudershausen et al. 2007; Rudershausen 2008a). In contrast, large numbers of black sea bass are caught and released in the recreational fishery; in 2009, for example, 89.7% of the 2.72 million recreationally caught black sea bass in the U.S. Atlantic were discarded

(NOAA 2010). Applying the correct discard mortality to this large number of fish has obvious implications for the assessment of this species.

Reducing discard mortality is a central tenet in modern fisheries management practices in U.S. marine waters. Our cumulative work on black sea bass shows that some gears and depths of capture have lower discard and discard mortality percentages than others. Depth and gear data for estimates of discard mortality are useful in assessments and can be used to condone or regulate those gears and fishing depths that reduce the percentage of dead discarded fish in the U.S. South Atlantic reef fishery.

Extension of Results

Preliminary results were presented at the March 2008 Fisheries Forum and at the NOAA Beaufort Lab in December 2008. Final results were presented to the Tidewater Chapter of the American Fisheries Society, March 2009 (Wilmington, NC), the South Atlantic Fishery Management Council, March 2009 (Jekyl Island, GA), and the Estuarine Research Federation, November, 2009 (Portland, OR).

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Literature Cited

Alós, J. Influence of anatomical hooking depth, capture depth, and venting on mortality of painted comber (*Serranus scriba*) released by recreational anglers. ICES Journal of Marine Science 65: 1620-1625.

Alversen, D.L., M.H. Freeburg, S.A. Murawski, and J.G. Pope. 1994. A global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper No. 339, 233 p.

Bacheler, N.M. and J.A. Buckel. 2004. Does hook type influence the catch rate, size, and injury of grouper in a North Carolina commercial fishery? Fisheries Research 69: 303-311.

Bartholomew, A. and J.A. Bohnsack. 2005. A review of catch and release angling mortality with implications for no-take reserves. Reviews in Fish Biology and Fisheries 15: 129-154.

Bugley, K., and G. Shepherd. 1991. Effect of catch-and-release angling on the survival of black sea bass. North American Journal of Fisheries Management 11: 468-471.

Burns, K.M., C.C. Koenig, and F.C. Coleman. 2002. Evaluation of multiple factors involved in release mortality of undersized red grouper, gad, red snapper, and vermilion snapper. More Marine Laboratory Technical Report No. 790, Sarasota, FL, 53 p.

Campbell, M.D., J. Tolan, R. Straus, and S.L. Diamond. 2010. Relating angling-dependent fish impairment to immediate release mortality of red snapper (*Lutjanus campechanus*). Fisheries Research 106: 64-70.

Coleman F.C., C.C. Koenig, G.R. Huntsman, J.A. Musick, A.M. Eklund, J.C. McGovern, R.W. Chapman, G.R. Sedberry, and C.B. Grimes. 2000. Long lived reef fishes: the grouper-snapper complex. Fisheries 25(3): 14–21.

Collier, C., and S. Stewart. 2010. Age sampling of the commercial snapper grouper fishery and age description of the black sea bass fishery in North Carolina. MARFIN Completion Report Grant NA06NMF4330057. North Carolina Division of Marine Fisheries, Morehead City, NC, 70 p.

Collins, M.R., J.C. McGovern, G.R. Sedberry, H.S. Meister, and R. Pardieck. 1999. Swim bladder deflation in black sea bass and vermilion snapper: potential for increasing postrelease survival. North American Journal of Fisheries Management 19: 828-832.

Davis, M.W. 2002. Key principles for understanding fish bycatch discard mortality. Canadian Journal of Fisheries and Aquatic Sciences 59: 1834-1843.

Davis, M.W. and M.L. Ottmar. 2006. Wounding and reflex impairment may be predictors for mortality in discarded or escaped fish. Fisheries Research 82: 1-6.

Diodati, P.J. and R.A. Richards. 1996. Mortality of striped bass hooked and released in salt water. Transactions of the American Fisheries Society 125: 300-307.

Dorf, B.A. 2003. Red snapper discards in Texas coastal waters-a fishery dependent onboard survey of recreational headboat discards and landings. American Fisheries Society Symposium 36: 155-166.

Feathers, M.G. and A.E. Knable. 1983. Effects of depressurization upon largemouth bass. North American Journal of Fisheries Management 3: 86-90.

Gitschlag, G.R. and M.L. Renaud. 1994. Field experiments on survival rates of caged and released red snapper. North American Journal of Fisheries Management 14: 131-136.

Guccione, D.V. 2005. Hooking mortality of reef fishes in the snapper-grouper commercial fishery of the southeastern United States. Masters thesis. University of North Carolina, Wilmington.

Hannah, R.W., S.J. Parker, and K.M. Matteson. 2008. Escaping the surface: the effect of capture depth on submergence success of surface-released Pacific rockfish. North American Journal of Fisheries Management 28: 694-700.

Hueter, R.E., C.A. Manire, J.P. Tyminski, J.M. Hoenig, and D.A. Hepworth. 2006. Assessing mortality of released or discarded fish using a logistic model of relative survival derived from tagging data. Transactions of the American Fisheries Society 135: 500-508.

Matthews, K.R. and R.H. Reavis. 1990. Underwater tagging and visual recapture as a technique for studying movement patterns of rockfish. American Fisheries Society Symposium 7: 168-172.

McGovern, J.C., G.R. Sedberry, H.S. Meister, T.M. Westendorff, D.M. Wyanski, and P.J. Harris. 2005. A tag and return study of gag, *Mycteroperca microlepis*, off the southeastern U.S. Bulletin of Marine Science 76(1): 47-59.

Morrissey, M.B., C.D. Suski, K.R. Esseltine, and B.L. Tufts. 2005. Incidence and physiological consequences of decompression in smallmouth bass (Micropterus dolomieu) after live-release angling tournaments. Transactions of the American Fisheries Society 134: 1038-1047.

Moser, J. and G.R. Shepherd. Seasonal distribution and movement of black sea bass (*Centropristis striata*) in the northwest Atlantic as determined from a mark-recapture experiment. Journal of Northwest Atlantic Fishery Science 40: 17-28

NOAA. 2010. Available at: http://www.st.nmfs.noaa.gov/st1/recreational/queries/catch/time_series.html

Patterson, W. F. III, G. W. Ingram, Jr., R. L. Shipp, and J. H. Cowan, Jr. 2000. Indirect estimation of red snapper and gray triggerfish mortality. Proceedings of the 53rd Annual Gulf and Caribbean Fisheries Institute, pp. 526-536.

Pollock, K.H. and W.E. Pine III. 2007. The design and analysis of field studies to estimate catch-and-release mortality. Fisheries Management and Ecology 14: 123-130.

Reeves, K.A. and R.E. Bruesewitz. 2007. Factors influencing the hooking mortality of walleyes caught by recreational angles on Mille Lacs, Minnesota. North American Journal of Fisheries Management 27: 443-452.

Rudershausen, P.J., J.A. Buckel, and E.H. Williams. 2007. Discard composition and release fate in the snapper and grouper commercial hook-and-line fishery in North Carolina, USA. Fisheries Management and Ecology 14: 103-113.

Rudershausen, P.J., E.H. Williams, J.A. Buckel, J. C. Potts, and C.S. Manooch III. 2008a. Comparison of reef fish catch-per-unit-effort and total mortality between 1970s and 2005-06 in Onslow Bay, NC. Transactions of the American Fisheries Society 137: 1389-1405.

Rudershausen, P.J., M.S. Baker, Jr., and J.A. Buckel. 2008b. Catch rates and selectivity among three trap types in the U.S. South Atlantic black sea bass commercial trap fishery. North American Journal of Fisheries Management 28: 1099-1107.

Rummer, J.L. 2007. Factors affecting catch and release (CAR) mortality in fish: insight into CAR mortality in red snapper and the influence of catastrophic decompression. Pp. 123-144 *in:* Red snapper ecology and fisheries in the U.S. Gulf of Mexico. W.F. Patterson, J.H. Cowan, G. Fitzhugh, and D.L. Nieland, eds. American Fisheries Society Symposium 60, 396 p. American Fisheries Society, Bethesda, MD.

Rummer, J.L. and W.A. Bennett. 2005. Physiological effects of swim bladder overexpansion and catastrophic decompression on red snapper. Transactions of the American Fisheries Society 134: 1457-1470.

SAS Institute. 1989. JMP, version 7.0. SAS Institute, Inc., Cary, North Carolina.

St. John, J. 2003. Is your fish "bent" and will it survive? Pp. 31-35 *In*: SPC Live Reef Fish Information Bulletin #11. Secretariat of the Pacific Community, Noumea, New Caledonia.

St. John, J. and C.J. Syers. 2005. Mortality of the demersal West Australian dhufish, *Glaucosoma hebraicum* (Richardson 1845) following catch and release: the influence of capture depth, venting, and hook type. Fisheries Research 76: 106-116.

SEDAR. 2003. Complete assessment and review report of South Atlantic black sea bass. South Atlantic Fishery Management Council, Charleston, SC, 60 p.

Sumpton, W.D., I.W. Brown, D.G. Mayer, M.F. McLennan, A. Mapleston, A.R. Butcher, D.J. Welsh, J.M. Kirkwood, B. Sawynok, and G.A. Begg. Assessing the effects of line capture and barotraumas relief procedures on post-release survival of key tropical reef fish species in Australia using recreational tagging clubs. Fisheries Management and Ecology 17: 77-88.

Wilde, G.R. 2009. Does venting promote survival of released fish? Fisheries 34(1): 20-28.

Wilson, R.R. and K.M. Burns. 1996. Potential survival of released groupers caught deeper than 40 m based on shipboard and in-situ observations, and tag-return data. Bulletin of Marine Science 58(1): 234-247.

Table 1. Relative survival percentage (± 95% confidence limits (CL)) for five species of reef fishes in increasingly more compromised release conditions (2a, 2b, 2c, 3, and 4) compared to assumed survival rate of 100% of conspecific fish in the best release condition (1). Survival rates of black sea bass are broken down by fish < 305 and ≥ 305 mm total length. The total length (TL) mean, standard deviation, and range is listed for each release group-species combination. See Methods section for description of release conditions.

Species	Condition	#Tagged	Mean TL	S.D. TL	TL Range	#Returned	% Survival	Lower 95% CL	Upper 95% CL
Black sea bass < 305 mm	1	1977	248.2	31.9	151 - 304	431	100	-	-
	2a	54	252.5	26.8	185 - 300	5	42.5	18.4	98.3
	2b	1186	248.4	32.2	148 – 304	273	105.6	92.4	120.7
	2c	19	234.2	30.5	170 – 285	2	48.3	13.0	179.6
	3	158	245.8	33.4	173 – 302	5	14.5	6.1	34.5
	4	62	228.9	34.2	172 – 300	2	14.8	3.8	58.0
Black sea bass ≥ 305 mm	1	519	337.1	26.0	305 – 430	154	100	-	-
	2a	17	338.5	23.7	305 – 385	2	39.6	10.7	146.7
	2b	526	350.2	36.6	305 – 515	147	94.2	77.8	114.0
	2c	4	373.8	40.7	325 - 420	0	0	-	-
	3	28	353.6	38.3	305 – 455	3	36.1	12.3	106.1
	4	5	348.8	55.2	304 – 442	1	67.4	11.6	391.0
Red porgy	1	735	350.4	37.8	250 - 460	29	100	-	-
	2a	2	375.0	49.5	340 - 410	0	0	-	-
	2b	604	365.7	38.9	260 – 580	24	100.7	59.3	171.1
	2c	2	375.0	7.1	370 - 380	0	0	-	-
	3	30	379.2	46.3	260 – 440	0	0	-	-
	4	36	371.8	32.5	269 - 440	0	0	-	-
White grunt	1	720	304.2	51.4	168 – 485	31	100	-	-
	2a	4	323.8	66.8	240 - 380	0	0	-	-
	2b	397	330.6	48.9	210 - 435	8	46.8	21.7	100.8
	2c	5	346.7	28.9	320 - 395	1	464.5	77.8	2772.6
	3	105	305.8	56.7	180 – 460	2	44.2	10.7	182.1

	4	133	291.3	60.0	178 - 460	0	0	-	-
Gray triggerfish	1	201	349.2	58.6	190 - 530	20	100	-	-
	2a	0	-	-	-	0	-	-	-
	2b	114	316.4	41.6	232 – 445	8	70.5	32.1	154.9
	2c	0	-	-	-	0	-	-	-
	3	10	328.7	44.0	250 – 405	0	0	-	-
	4	7	335.7	57.6	282 - 405	0	0	-	-
Vermilion snapper	1	97	299.8	48.9	198 – 430	1	100	-	-
	2a	17	304.4	80.1	200 – 470	0	0	-	-
	2b	299	331.1	58.9	168 – 470	8	259.5	32.9	2048.9
	2c	18	295.2	46.7	232 – 410	0	0	-	-
	3	9	329.8	51.3	208 – 370	0	0	-	-
	4	8	360.3	81.1	248 – 490	0	0	-	-

Table 2. Numbers caught, discarded (sub-legal), and dead discarded black sea bass as a percentage of sub-legal black sea bass catch from 25 data sets collected from the commercial (C) and recreational (R) fisheries in Onslow Bay, NC. Data sets do not include black sea bass that were tagged in this study, owing to potential effects of tagging as a proxy for venting (venting is not required or widely practiced in the study area). Data are broken down by gear type (hook and line with electric reels (HL-E), hook and line with manual reels (HL-M) and traps with legal mesh sizes) and depth (m). The commercial and recreational minimum size limits for black sea bass in the U.S. South Atlantic are 254 and 305 mm total length, respectively. The percent discard mortality for each gear-depth combination in the table is computed by applying the relative survival percentages from the tagging model (using data for black sea bass < 305 mm total length) to the fish released in various conditions in the collection of each data set. Percent discard mortality is computed only from sub-legal fish for that fishery type (commercial vs. recreational).

Gear	Fishery	Depth (m)	# caught	# Sub-legal	% Sub-legal	# Dead sub-legal discards	Discard mortality as % of sub-legal catch
HL-E	C	29	198	23	11.6	0.7	3.5
HL-E	C	31	315	87	27.6	0	0
HL-E	R	20	42	41	97.6	2.02	4.9
HL-E	R	31	112	69	61.6	4.8	6.9
HL-M	R	20	259	218	84.2	10.91	5.0
HL-M	R	31	332	200	60.2	11.1	5.6
Trap	C	11	218	20	9.1	0	0
Trap	C	12	120	4	3.3	0	0
Trap	C	13	416	53	12.7	0	0
Trap	C	14	348	52	14.9	0	0
Trap	C	15	123	3	2.4	0	0
Trap	C	16	143	16	11.2	0.9	5.3
Trap	C	17	15	0	0	0	0
Trap	C	18	92	8	8.7	0	0
Trap	C	19	113	4	3.5	0	0
Trap	C	20	200	10	5.0	0	0
Trap	C	21	55	6	10.9	0	0
Trap	C	22	175	16	9.1	0	0
Trap	C	23	182	12	6.6	0	0
Trap	C	24	551	57	10.3	0.7	1.3

Trap	C	25	222	11	5.0	0	0
Trap	C	26	507	16	3.2	0	0
Trap	C	27	409	43	10.5	1.5	3.8
Trap	C	28	44	1	2.3	0	0
Trap	C	29	462	29	6.3	0.9	3.3

Figure 1 – Time-at-large for five species of reef fish tagged and released in Onslow, Bay, North Carolina. For individuals recaptured on multiple occasions, the longest time-at-large was used to construct the graph.

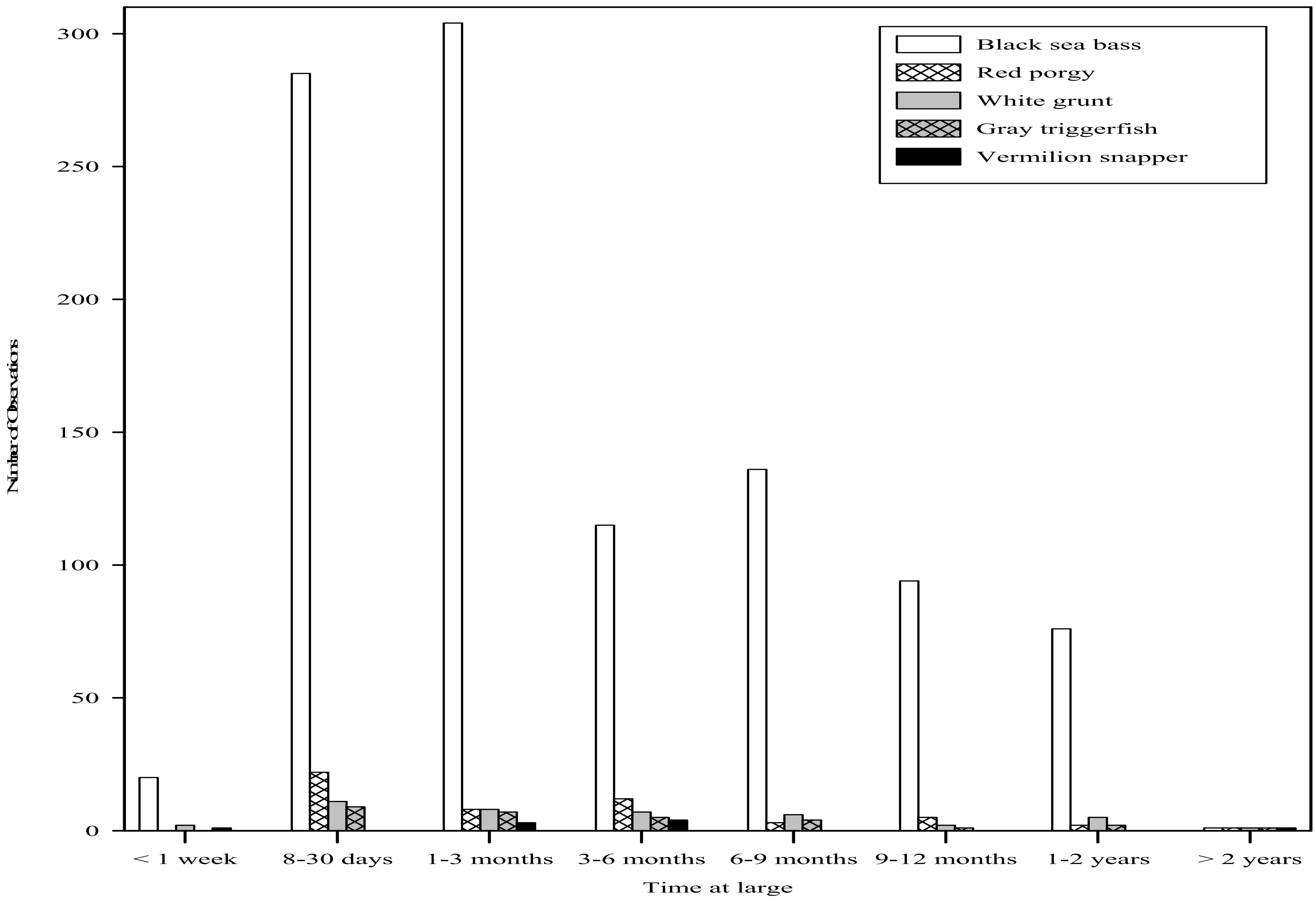

Figure 2. Relationship between black sea bass mortality percentage (y-axis) and depth (m) (x-axis) for six hook and line and 19 trap data sets (traps with legal mesh sizes). Percent mortality of black sea bass for each gear-depth combination was computed from discarding and observing the release condition (described in Methods) of sub-legal black sea bass from the commercial (< 254 mm minimum total length) and recreational fisheries (< 305 mm minimum total length). Data sets did not include tagged black sea bass, owing to the potential for tagging to serve as a form of venting.