Estimating Reef Fish Discard Mortality Using Surface And Bottom Tagging: Effects Of Hook Injury And Barotrauma

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Estimating reef fish discard mortality using surface and bottom tagging: effects of hook injury and barotrauma

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Abstract: We estimated survival rates of discarded black sea bass (*Centropristis striata*) in various release conditions using tag–recapture data. Fish were captured with traps and hook and line from waters 29–34 m deep off coastal North Carolina, USA, marked with internal anchor tags, and observed for release condition. Fish tagged on the bottom using SCUBA served as a control group. Relative return rates for trap-caught fish released at the surface versus bottom provided an estimated survival rate of 0.87 (95% credible interval 0.67–1.18) for surface-released fish. Adjusted for results from the underwater tagging experiment, fish with evidence of external barotrauma had a median survival rate of 0.91 (0.69–1.26) compared with 0.36 (0.17–0.67) for fish with hook trauma and 0.16 (0.08–0.30) for floating or presumably dead fish. Applying these condition-specific estimates of survival to non-tagging fishery data, we estimated a discard survival rate of 0.81 (0.62–1.11) for 11 hook and line data sets from waters 20–35 m deep and 0.86 (0.67–1.17) for 10 trap data sets from waters 11–29 m deep. The tag-return approach using a control group with no fishery-associated trauma represents a method to accurately estimate absolute discard survival of physoclistous reef species.

Résumé : Nous avons estimé les taux de survie de bars noirs (*Centropristis striata*) rejetés dans différentes conditions à l'aide de données de marquage–recapture. Les poissons ont été pris par piège et par ligne et hameçon à des profondeurs allant de 29 m à 34 m, au large de la Caroline du Nord (États-Unis) et marqués avec des étiquettes à ancrage internes, puis leur état après le lâcher a été observé. Des poissons marqués au fond à l'aide d'ARAP ont servi de groupe témoin. La comparaison des taux de retour relatifs des poissons pris par piège relâchés à la surface et au fond a donné un taux de survie estimé de 0,87 (95 %; intervalle de crédibilité : 0,67–1,18) pour les poissons relâchés à la surface. Une fois les données ajustées pour tenir compte des résultats de l'expérience de marquage sous-marin, les poissons présentant des signes de barotraumatisme avaient un taux de survie médian de 0,91 (0,69–1,26) comparativement à 0,36 (0,17–0,67) pour les poissons présentant des traumatismes associés aux hameçons et 0,16 (0,08–0,30) pour les poissons flottants/probablement morts. En appliquant ces estimations de la survie pour des conditions précises à des données sur des pêches sans marquage, nous avons estimé un taux de survie des poissons rejetés de 0,81 (0,62–1,11) pour 11 ensembles de données de pêche avec ligne et hameçon dans des eaux de 20 m à 35 m de profondeur, et de 0,86 (0,67–1,17) pour 10 ensembles de données de pêche au piège dans des eaux de 11 m à 29 m de profondeur. L'approche d'étiquetage-retour avec groupe témoin sans traumatisme associé à la pêche constitue une méthode permettant d'estimer avec exactitude les taux de survie absolus après rejet d'espèces de poissons récifaux physoclistes. [Traduit par la Rédaction]

Introduction

The quantity and disposition of discarded fishes is a ubiquitous issue in fisheries worldwide (Alverson et al. 1994). In many fisheries, there is an unknown rate of mortality for individuals that are caught with fishing gear and then discarded (Davis 2002). Unaccounted discard mortality negatively biases estimates of fishing mortality and creates the potential for unsustainable harvest levels.

Many reef fisheries around the world are experiencing increased numbers of fish being caught and released as a result of stricter management measures (St. John and Syers 2005; Rudershausen et al. 2007; Hochhalter and Reed 2011). Reef-associated fishes may not survive catch and release because many are physoclists whose gas bladders rupture during capture. This may render them unable to return to the bottom or result in delayed mortality after they do return to the bottom (Hochhalter and Reed 2011). In addition to the effects of barotraumas, released fish may die from gear trauma, stress, predation, or a combination of these factors (Davis 2002; St. John and Syers 2005; Rummer 2007). It is assumed that the benefits of regulations offset rates of discard mortality, but this will not always be the case (Coggins et al. 2007). Improving estimates of how many caught and released fish die is an important step in determining the effectiveness of regulations.

In the United States, the South Atlantic Fishery Management Council uses size limits, possession limits, closed seasons, and area closures to manage demersal reef fishes from North Carolina to Florida. A high percentage of reef fish captured in North Carolina are discarded because they are either undersize (Rudershausen et al. 2007) or out of season. The black sea bass (*Centropristis striata*) is one of the most recreationally and commercially important reef fishes in the US South Atlantic. It is relatively abundant and can be efficiently captured with both traps and hook and line over a wide range of sizes (Rudershausen et al 2008*a*, 2008*b*). Many of the regulations described above have led to a high discard rate of hook-caught black sea bass. In 2009, for example, 89.7% of the 2.72 million recreationally caught black sea bass in the US Atlantic were released (NOAA 2010). Given the large number of releases, it is imperative to

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have robust estimates of discard mortality by gear to increase the accuracy and precision of stock status estimates.

Mortality proxies such as obvious barotraumas, floating, hook trauma, scale loss, or poor reflex responses have been used to infer mortality in many fish species (Beverton et al. 1959; Kaimmer and Trumble 1998; Patterson et al. 2000; Rudershausen et al. 2007; Davis 2007), but the condition and behavior of 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 that took into account hooking mortality rates and assuming all fish with external signs of barotrauma die (Rudershausen et al. 2007). 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 that outside of it (Davis 2002; Pollock and Pine 2007). Tagging methods can be used to estimate rates of mortality for released fish (Trumble et al. 2000) but care must be given to having a control group (Hueter et al. 2006; Pollock and Pine 2007); additionally, the various tagging treatments need to be distributed evenly in space if there will be spatial heterogeneity in tag–recapture effort.

Here, we estimate discard survival of black sea bass using a unique tagging approach. Our methodology represents a substantial improvement in estimating discard survival of reef fishes with physoclistous bladders in that we tagged fish on the seafloor to establish a group of control fish that were not subject to potential sources of mortality. Return rates of these control fish were then used to estimate discard survival of individuals in three compromised conditions: barotrauma, hook trauma, and floating. Lastly, to estimate discard survival in commercial and recreational black sea bass fisheries, we applied our estimates of survival by condition to numbers in each condition category released during fishing operations independent of tagging trips.

Methods

Study area

We tagged, released, and recaptured black sea bass at reef habitats in Onslow Bay, North Carolina, USA. These habitats were spatially separated and are visited by commercial, recreational, and charter boat fishermen (Rudershausen et al. 2008*a*, 2008*b*). The depth range of tagging (29–34 m) represented approximately 15 km horizontal extent. The depth and horizontal range attempted to balance two considerations: (*i*) remaining relatively close to shore to maximize the tag-return rate, and (*ii*) fishing in waters deep enough where discarded black sea bass exhibit a wide range of release conditions. Further, this narrow depth range did not allow for any changes in release condition with depth; this is important because fishing effort can be greater closer to port, resulting in more tag returns from fish released in good conditions in shallow water.

Estimates of discard survival by release condition

A control group of tagged black sea bass with no mortality associated with the fishing process was needed to estimate absolute discard survival of tagged black sea bass in different release conditions. Our control group was trap-caught black sea bass that were removed from traps by SCUBA divers, tagged, and released on the bottom. Thus, these fish did not experience any of the typical sources of mortality in discarded reef fish such as hook trauma, predation in the water column during descent, deck trauma, or pressure trauma. Simultaneous with bottom tagging, a second group of trap-caught black sea bass were brought to the surface and fish in the best condition (condition 1; see below) were tagged and released. Surface and bottom-tagged fish were released in the same locations or areas very close to one another during six tagging trips. We made directed trips at least 3 days after release to recapture tagged black sea bass and fished with the same effort at locations within a site where black sea bass were released at surface and bottom if there were small differences between release locations. Control fish were not released during the large-scale study (described below). We assumed the differences in survival between best-condition fish released at the surface and bottom-tagged fish applied to the large-scale tagging study.

A large-scale tagging experiment was conducted to determine the discard survival rates of fish released at the surface in various conditions. For this experiment, black sea bass were captured across all seasons of the year with three gears commonly used in commercial, recreational, and headboat fisheries for reef species: electric hook and line, manual hook and line, and traps. Commercial fishermen can use any of these gears to capture black sea bass in the US South Atlantic while recreational fishermen can use either type of hook and line. Hook and line sampling used rods, and manual and electric reels spooled with braided line. Terminal tackle for hook and line fishing consisted of rigs made from 91 kg monofilament line connecting a 540 g lead sinker and two natural-baited J hooks ranging from 2/0 to 7/0 in size. These hook sizes and the J-hook style typified those used for reef fishing in the US South Atlantic at the time of the study. For hook-and-line caught black sea bass, the hook was removed using a custom-made de-hooking tool. Square traps were made from 12-gauge vinyl-coated square mesh with two funnel entrances on opposite sides and a bait well extending the full depth of the trap; these traps typify those used in the commercial fishery in this region. Trap soak times ranged from 1 to 18 h, typical of the black sea bass trap fishery in the US South Atlantic.

For each tagged fish, we recorded total length (mm), hook location for fish captured with hook and line, presence or absence of visible barotrauma (trapped fish and hooked fish), tag number, and release condition as described below. Black sea bass ≥ 150 mm total length were marked with Floy FM-89SL internal anchor tags. A small hole was made with a scalpel blade to insert the disc part of the tag. The message on each tag included the tag number, a toll-free phone number, the reward amount ($5), and a message to "cut tag" so that the streamer could be removed but the disc left in non-legal fish. We mimicked typical fishing operations in the US South Atlantic by not using venting or descent-assisting devices.

Release conditions and behaviors were modified from Patterson et al. (2000) and were as follows: (1) alive, no hook trauma or visible barotrauma, and swam down; (2) alive, with visible barotrauma (e.g., stomach protruding into mouth cavity), and swam down; (3) alive, with hook trauma (non-jaw hooking) (regardless of barotrauma), and swam down, and; (4) floating at the surface or presumed dead, regardless of trauma. Fish in condition 1 were separated from those in conditions 2 and 3 because 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) compromise the ability of physoclistous fishes to survive release. The inability of floating fish to orient themselves and then submerge has been used as a proxy for mortality (Collins et al. 1999; Davis and Ottmar 2006; Rudershausen et al. 2007; Hannah et al. 2008).

Effects of tagging

Release of gas from the abdominal cavity occurred during tagging of black sea bass. Internal anchor tags may vent reef fish and produce higher survival rates as a result of fish being able to swim back to the bottom. There might also be higher survival rates within a condition category from the tagging and thus the venting process. We performed two tests to evaluate these possibilities. First, we used a chi-square contingency test to compare the frequencies of floating and swimming fish between 49 tagged and 50 untagged black sea bass released over the same reef site in the 29–34 m depth range. Second, within the relative risk model (described below), we examined whether discard survival of fish with barotrauma (condition 2) 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 trips when each condition was released. This analysis was conducted with condition 2 black sea bass because this was the only compromised release group with sufficient sample sizes of fish that were recaptured twice. Like for the large-scale tagging experiment, estimates of survival were adjusted using return rates of control (bottom-tagged) fish.

Estimates of discard survival for non-tagging fishery data sets

We estimated discard survival of released black sea bass from recreational and commercial data where this species was caught with hook and line and traps in Onslow Bay. On these trips, we observed released black sea bass with the same release conditions described above but did not tag them. Separate non-tagging trips were used to estimate discard survival in the fishery given the potential effect of venting from tagging on release condition. Hook and line data were collected from depths from 20 to 35 m and included data collected with both electric and manual reels. Trap data were collected in waters from 11 to 29 m deep. The maximum depths of collection with these two gears represent the rough maximum depths that they are used to capture black sea bass in Onslow Bay (P.J. Rudershausen, personal observation).

Data analysis

To inform estimates of discard survival, we used data from tag returns caught during research trips as well as from commercial, recreational, and charter boat sectors of the fishery. Data on releases were combined across trips from the large-scale tagging study because of small sample sizes for some of the release groups on individual trips. All recaptured fish on research trips were re-released and observed for a new release condition for data to determine effects of venting. Recapture events for an individual fish were assumed to be independent.

For the large-scale tagging study, we determined if black sea bass tag-return data could be combined across (*i*) traps and hook and line, and (*ii*) manual and electric reels. For the first pair of gears, to ensure that 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 commercial captain released both hook and line and trap-caught fish during the experiment. Additionally, we only used fish caught and tagged from 38 mm mesh traps to ensure that similar size distributions of trapped and hooked fish were available for recapture. A 2 × 2 contingency test of condition 1 black sea bass was used to compare frequencies of returns from each gear type; the two columns were the number returned and not returned and the two rows were the number tagged and released after capture by hook and line (n = 10 and 31 in the two respective cells) and traps (n = 313 and 1183 in the two respective cells). 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 did not have different return rates. For the second pair of gears, we restricted the analysis to a small (~1 km^2) spatial area where we released fish caught with both manual and electric reels. A contingency test of condition 1 black sea bass was also used to compare frequencies of returns from each of these gear types; the two columns were the number returned and not returned and the two rows were the number tagged and released after capture by manual reels (n = 3 and 7 in the two respective cells) and electric reels (n = 6 and 4 in the two respective cells). The result of this contingency test was non-significant ($\chi^2 = 0.81$; $p = 0.369$); manually caught and electrically caught condition 1 black sea bass did not have different return rates. The results from these two contingency tests justified combining data across all gears for estimating relative risk by condition.

We estimated discard survival of fish released for the tagging experiments using relative risk in a Bayesian framework (Woodworth 2004). Relative risk (RR) of fish released in compromised categories was estimated from the number of fish released (N) and returned in each condition (C) as follows:

$$\mathrm{RR} = \frac{C_n/N_n}{C_1/N_1}$$

where C_n/N_n is the return rate of fish in compromised category n, and C_1/N_1 is the return rate of fish in the best condition group. To estimate absolute survival with this approach, we assumed that control (bottom-tagged) fish survived as well as those never caught, fish among different conditions had the same survival after 3 days of recovery, and catchability and tag reporting rates were the same among fish in different release conditions (Hueter et al. 2006). We used only first recaptures to compute survival of fish in each condition for the bottom tagging and large-scale tagging experiments.

We conducted the bottom-tagging experiment to determine if the best condition fish released at the surface had survival similar to controls. During the bottom tagging experiment, it was not logistically possible to release the same number of fish in each treatment (surface vs. bottom-tagged) on each trip (i.e., there was spatial heterogeneity in treatments) or maintain similar recapture effort at each release site. Thus, we were unable to pool data across trips for this study given that increased effort at release site A relative to release site B could bias return rates for the treatment with higher releases at site A. Values for relative risk were estimated for each tagging trip in the bottom tagging experiment. Relative risk was estimated using the trip-specific survival estimates weighted by the number of fish recaptured from each bottom tagging trip. Because the RR of surface-released fish to control fish was <1 (see Results), we used this value to adjust relative survival rates from the large-scale tagging study to estimate absolute discard survival for each release condition (see Kaimmer and Trumble 1998 for similar approach).

RR modeling was performed in OpenBUGS software (Spiegelhalter et al. 2011). We assigned a beta prior distribution (a and $b = 0.5$) to the probability of tag returns for each condition in each tagging experiment (Woodworth 2004). The number of tag returns in each experiment was defined as a binomially distributed variable with the probability of tag returns described above and the number of trials equal to the number of tagged fish released in each condition. Estimates of discard survival for 11 non-tagging hook and line data sets and 10 trap data sets were made within the model used to estimate RR. For these non-tagging fishery data sets, we assigned an uninformative Dirichlet prior distribution to the probability of releasing a fish in each surface release condition: four for hook and line and three for traps. Gear-specific probabilities for surface release conditions were estimated using a multinomial distribution on the observed proportions of fish in each condition and the overall number of fish released. Data set specific survival rates were calculated from the probabilities of capturing fish in each condition multiplied by condition-specific RR values from the large-scale tagging experiment. The assumption in applying survival estimates from tagging to estimate survival rates for non-tagging data are that condition-specific survival rates over the 29–34 m depth range apply to other depths.

We ran the full probabilistic model using three Markov chains with a burn-in period of 10 000 iterations, then generated 100 000 updates of the model with every 10th iteration saved. See Supplemental materials[1] for model code.

[1]Supplementary material is available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/cjfas-2013-0337.

Table 1. Numbers of tagged and returned black sea bass (*Centropristis striata*) and median discard survival (with 2.5% and 97.5% credible intervals (CI)) by condition category from two experiments conducted in Onslow Bay, North Carolina, USA.

Experiment	Condition	Description of compromised condition	No. tagged	No. returned	2.5% CI survival	Median discard survival	97.5% CI survival
Bottom tagging study: Survival of surface versus bottom-released trap-caught condition 1 fish	1, bottom released	Control, best condition	296	106			
	1, surface released	Swam down, no visible barotrauma	280	75	0.67	0.87	1.18
Large-scale study: Survival of compromised and condition 1 fish released at surface	1, surface released	Swam down, no visible barotrauma	2496	585			
	2, surface released	Swam down, visible barotrauma	1712	420	0.69	0.91	1.26
	3, surface released	Swam down, hook trauma	94	9	0.17	0.36	0.67
	4, surface released	Floated, dead	253	11	0.08	0.16	0.30

Note: Condition categories: 1, fish in best condition with no signs of trauma and swam down or were bottom released; 2, external signs of barotrauma but swam down; 3, hook trauma but swam down; 4, floating or presumed dead.

For hook and line and trap data sets, we tested the relationship between median release survival estimated from the model run and water depth. This analysis was conducted with Spearman rank correlation.

Results

Estimates of discard survival by release condition

For the bottom tagging study, 75 out of 280 surface-released fish and 106 out of 296 bottom-tagged fish were recaptured. The median estimate of relative risk was 0.87 with moderately wide 95% credible intervals (CI) (0.67–1.18). Thus, survival of surface-released fish in condition 1 was 87% (Table 1).

A total of 4555 black sea bass were tagged and 1025 returned at least once, resulting in an overall tag-return rate of 22.5% in the large-scale tagging experiment. The return rate of black sea bass that swam down with obvious barotrauma (condition 2) was similar to the return rate of fish with no obvious barotrauma (condition 1), resulting in similar estimates of relative risk (0.87 and 0.91) with widely overlapped credible intervals (Table 1). Estimates of relative risk declined for released fish that swam down with hook trauma (condition 3) (0.36) or floated and presumably died (condition 4) (0.16; Table 1). Thus, hook trauma and the inability to submerge led to higher mortality relative to fish that showed outward signs of barotrauma but were able to submerge.

Effects of tagging

Using internal anchor tags to mark black sea bass brought to the surface affected their release behavior but not return rates. A higher percentage of tagged individuals swam down (26/31; 83.9%) than untagged individuals (15/31; 48.4%) (χ^2 = 8.71; p = 0.003). The credible intervals of relative risk of condition 2 fish after a first (vented) release (median: 0.91; CI: 0.69–1.26; number of recaptures in Table 1) and second (unvented) release (median: 1.00, CI: 0.80–1.25; 77 recaptures out of 168 unvented condition 2 fish relative to 91 recaptures of 199 vented condition 1 fish) widely overlapped. Thus, venting via tagging influenced the ability of fish to submerge, but venting did not influence the estimate of relative risk for condition 2 fish.

Estimates of discard survival by fishery

The majority of released black sea bass from 21 non-tagging data sets were in conditions 1 and 2 (Table 2). Averaged across all data sets for each gear, median discard survival was 0.81 for hook and line and 0.86 for traps (Table 2). Rates of median discard survival by data set decreased with increasing depth (Fig. 1), but the relationship between median survival and depth was not significant for hook and line (Spearman r = –0.319; p = 0.339) or for traps (Spearman r = –0.211; p = 0.559).

Discussion

Our study provides robust estimates of discard survival for an economically important United States east coast reef fish. Robust estimates were possible for two reasons. First, the high tag return in this study allowed us to estimate discard survival of black sea bass with a level of precision that would not have been possible with the ~10% tag-return rates typical of other reef fish studies (e.g., Wilson and Burns 1996; McGovern et al. 2005; Moser and Shepherd 2009; Sumpton et al. 2010; but see Hochhalter and Reed 2011). Second, the control group gives us confidence in the accuracy of our estimates of discard survival.

Other studies have used control groups to estimate discard mortality of reef fish in cages or the laboratory. Pribyl et al. (2012) caught black rockfish (*Sebastes melanops*) in shallow water with no barotrauma at capture and then applied a treatment (capture and recompression) and control (no capture) within hyperbaric chambers. Butcher et al. (2012) used laboratory-held snapper (*Pagrus auratus*) to create control and barotrauma treatments that were held in field cages to assess survival. We are not aware, however, of any other discard mortality study on physoclistous reef fish that controlled for the effects of barotrauma and other factors known to cause discard mortality in situ. We encourage others studying discard mortality in the field to develop control groups either by tagging at depth (Hislop and Hemmings 1971; this study) or using other novel approaches.

Effects of fishing on discard survival of black sea bass

It has been assumed that reef fish with obvious barotrauma die after release (Rudershausen et al. 2007), but, over the depths we tagged, this assumption is not valid. Most black sea bass with external signs of barotrauma, which were able to swim down, 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; 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). Based on our results, however, these barotraumas do not lead to high mortality in black sea bass over our study's range of tagging depths. There is increasing evidence that barotrauma is not a good indicator of mortality in other reef fishes (Jarvis and Lowe 2008; Hochhalter and Reed 2011; Hannah et al. 2012).

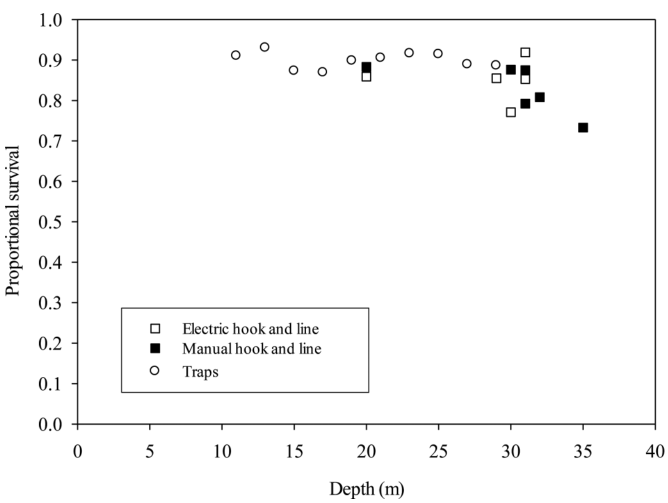
A major assumption of our approach is that fish released in the best condition survived as well as those never caught. The black sea bass fishery is shallow enough that we were able to use SCUBA to tag fish on the bottom, allowing us to have a control group to satisfy this assumption and to estimate rates of discard survival for more compromised conditions. Similarly, Hislop and Hemmings

Table 2. Depths, numbers by release condition, and estimates of discard survival (median, 2.5% and 97.5% credible intervals (CI)) of black sea bass (*Centropristis striata*) captured and observed in four release conditions from 11 recreational (R) and commercial (C) hook and line (HL) data sets and three release conditions from 10 commercial trap data sets collected in Onslow Bay, North Carolina, USA.

Gear	Fishery	Depth (m)	No. released: total	No. released: condition 1	No. released: condition 2	No. released: condition 3	No. released: condition 4	2.5% CI survival	Median survival	97.5% CI survival
HL-M	R	20	201	95	82	22	2	0.63	0.82	1.12
HL-E	R	20	12	12	0	0	0	0.59	0.79	1.10
HL-E	C	29	20	10	8	2	0	0.59	0.80	1.10
HL-M	R	30	52	8	38	3	3	0.61	0.81	1.12
HL-E	R	30	31	4	19	3	5	0.52	0.71	1.01
HL-M	R	31	200	40	134	12	14	0.62	0.81	1.12
HL-M	R	31	20	3	13	1	3	0.53	0.73	1.04
HL-E	C	31	60	17	40	3	0	0.65	0.85	1.17
HL-E	R	31	69	8	49	9	3	0.60	0.79	1.09
HL-M	R	32	61	13	34	9	5	0.56	0.75	1.04
HL-M	R	35	14	1	9	1	3	0.47	0.68	0.98
HL-Overall			730	201	426	65	38	0.62	0.81	1.11
Traps	C	11	24	24	0	—	0	0.65	0.84	1.14
Traps	C	13	103	103	0	—	0	0.67	0.86	1.17
Traps	C	15	20	19	0	—	1	0.61	0.81	1.11
Traps	C	17	7	7	0	—	0	0.58	0.80	1.12
Traps	C	19	15	15	0	—	0	0.63	0.83	1.14
Traps	C	21	19	19	0	—	0	0.65	0.84	1.15
Traps	C	23	63	59	3	—	1	0.66	0.85	1.16
Traps	C	25	27	26	1	—	0	0.65	0.85	1.16
Traps	C	27	41	36	3	—	2	0.63	0.82	1.13
Traps	C	29	26	25	0	—	1	0.63	0.82	1.12
Traps-Overall			344	332	7	—	5	0.67	0.86	1.17

Note: Data sets are further separated by hook and line with manual reels (HL-M) and hook and line with electric reels (HL-E). These were non-tagging trips. Condition categories: 1, fish in best condition with no signs of trauma and swam down; 2, external signs of barotrauma but swam down; 3, hook trauma but swam down; 4, floating or presumed dead.

Fig. 1. Estimates of discard survival of black sea bass (*Centropristis striata*) by depth from 21 recreational and commercial fishing data sets from Onslow Bay, North Carolina, USA. Data sets are separated by gear (electric hook and hook and line (open squares), manual hook and line (filled squares), and traps (circles)). Survival estimates include live and dead releases.



(1971) used divers to remove and tag haddock (*Melanogrammus aeglefinus*) from a trawl codend on the seafloor; these fish were used as a control group to which to compare catch and release survival of treated fish that were fish brought to the surface and tagged.

Previous studies have used tagging to estimate discard survival of fishes (Beverton et al. 1959; Kaimmer and Trumble 1998; McGovern et al. 2005; Hueter et al. 2006), but estimates have the potential to be biased if spatial heterogeneity in release treatments and recapture effort occurs. For example, Kaimmer and Trumble (1998) distributed tagging treatments evenly among release areas to avoid bias from spatial heterogeneity in fishing effort during tag recoveries. For physoclistous fishes, depth is a concern because fish in more compromised condition might occur more frequently in deeper water, an area of potentially reduced effort, leading to bias in returns of fish in more favorable conditions. In our study, we restricted the tagging to a discrete depth to prevent this bias. However, spatial heterogeneity was an issue in the bottom tagging experiment because the surface and bottom-tagged fish were not distributed evenly among release areas. Because of this, we estimated discard survival on a trip-specific basis to avoid differential recapture effort among those sites. Future work to estimate discard survival of reef fishes should distribute release conditions evenly among tagging locations if equal recapture effort among these locations is not possible (Kaimmer and Trumble 1998).

Venting is not widely practiced in the North Carolina reef fishery and may not be effective for promoting survival of released fishes (Wilde 2009), but it was important for us to estimate whether venting from our tag application influenced estimates of survival. Our data indicate that venting via tagging reduces the percentage of floating fish over our tagging depths. Therefore, we used non-tagging data to obtain estimates of numbers by condition category within each fishery; this is important to take into account because the lowest survival was found in the floating or dead condition category. In a study conducted over a similar depth range, Collins et al. (1999) also found that venting increased the proportion of black sea bass that could submerge after release. It does not appear that survival within a release category was influenced by venting however, as vented and unvented condition 2 fish had similar estimates of survival. Fishermen would not know which black sea bass float (condition 4) before venting and more damage could be done to fish with external signs of barotrauma that would have been able to swim down on their own (condition 2 fish). Thus, there may be little benefit of venting to improve the release outcome of black sea bass over the depths that we tagged. To address this question, we recommend that discard survival of black sea bass be estimated and compared between the following treatments: vented with a venting tool, submerged with a descending device, or released without any assistance (see Sumpton et al. 2010 for a similar study).

In contrast to the minor effect of barotrauma over the depths we tagged, the majority of fish with hook trauma (condition 3) died. This is consistent with observations of the effects of hook trauma across a range of species (e.g., Bugley and Shepherd 1991; Diodati and Richards 1996; Bartholomew and Bohnsack 2005; St. John and Syers 2005; Reeves and Bruesewitz 2007; Alós 2008). The low survival rate appears to be due to hook damage to well-perfused vital organs (e.g., heart, gills, stomach, and liver), which increases the rate of mortality relative to peripheral areas such as the jaw (Diodati and Richards 1996). Condition 3 and 4 fish in our study died from hook trauma or barotrauma, or both of these trauma types.

Discard survival in hook and line and trap fisheries

Rates of discard survival for fishes with physoclistous bladders depend on the depths over which fish are captured (Bartholomew and Bohnsack 2005). Over depth ranges of 20–23 m and 29–35 m, Collins et al. (1999) used holding cages and estimated hook-and-line caught black sea bass survival to be 85% and 88%, respectively. These estimates are similar to ours and, like our study, incorporate immediate and delayed mortality. We found that discard survival was higher in the trap than hook and line fishery, likely due to depth differences between the fisheries and the lack of hook trauma in trapped fish. Rates of discard survival were similar between hook-caught fish retrieved with manual and electric reels at similar depths. Given the high survival over a broad depth range where the fishery occurs, as well as high variability in survival rates over deeper waters, we did not find a negative relationship between survival and depth for hook and line or trapping. In contrast, previous studies investigating depth-related rates of discard mortality in this species (Collins et al. 1999) and other reef fishes (e.g., Collins et al. 1999; McGovern et al. 2005; St. John and Syers 2005; Stewart 2008; Diamond and Campbell 2009; Hannah et al. 2012) have found a significant effect of depth, but the largest drop in survival occurred in depths greater than depths investigated in our study.

An assumption of our estimates of discard survival in each fishery is that condition-specific estimates over the depths of our tagging study apply to non-tagging data collected over other depths. Owing to the changing effects of barotrauma with depth, the fishery-specific discard mortality rates (Fig. 1; Table 2) are likely most accurate for depths similar to those over which we tagged. Death from hook trauma (condition 3) would likely not differ by depth. Also, the percentage of fish in condition 4 would be lowest in shallow water and greatest in the deepest water locations, so the changing effects of barotrauma are taken into account, to an extent, in our estimates of discard survival in the fisheries. Our work does not provide information on how survival of condition 1 and 2 fish would differ in waters shallower or deeper than our study depths.

Our data suggest that the ~10% reduction in survival we made for condition 1 and 2 fish caught over the 29–34 m depth range is likely not necessary for shallower waters. The decreased capture of condition 1 fish released at surface relative to bottom-tagged fish is most likely due to barotrauma even though there were no external signs. The effects of barotrauma are known to lessen in shallower waters for physoclistous fishes, so condition 1 releases in shallower water may have increased survival. For example, the median rate of survival we computed from hook and line data sets (0.81) is lower than the rate (0.98) found for black sea bass, < 305 mm total length, caught with hook and line over depths between 6 and 12 m in New England (Bugley and Shepherd 1991). Additionally, Rudershausen et al. (2007) found that over depths averaging 21 m only 4.2% of trapped black sea bass had external signs of barotrauma. This contrasts with a rate of 37.6% for fish brought to the surface in our study. Lastly, P.J. Rudershausen (unpublished data) found that tag-return rates of black sea bass brought to surface but lowered to bottom in cages and surface-released fish had similar return rates, so predation while descending to bottom does not appear important. Thus, the survival adjustment to condition 1 fish may not be necessary when applied to release data over shallower depths.

It is important to monitor depth information for caught-and-released physoclistous fish to reliably estimate the number of dead discards. Currently, recreational surveys in the US South Atlantic reef fishery do not collect depth information, but the majority of black sea bass caught and released in this region are from that sector. Black sea bass are most commonly captured over shallower depths in the commercial trap fishery in North Carolina than the 29–34 m tagging depth range (Rudershausen et al. 2007; Rudershausen et al. 2008*b*; Collier and Stewart 2010) and at roughly similar depths as our tagging study in the commercial hook and line fishery (Rudershausen et al. 2008*a*; Collier and Stewart 2010). It is important to note that our discard survival estimates by gear include the number of live fish that will die and dead fish released; often, estimates of discard survival are needed that apply to live fish releases only since dead discards are accounted for in separate surveys. Discard survival of live releases can be estimated from the number and condition-specific survival estimates for fish in conditions 1, 2, and 3.

Use of proxies to estimate discard survival

Given that discard survival estimates from experiments are often not available for many fishes, there is interest in using release conditions as proxies of survival or mortality (Davis 2002). Swimming behavior and submergence after release and other conditions (e.g., reflex impairment, barotrauma, hook trauma, bleeding, scale loss) have been used as proxies of survival-mortality in discard mortality studies of fishes (Beverton et al. 1959; Kaimmer and Trumble 1998; Patterson et al. 2000; Rudershausen et al. 2007; Davis 2007; Hannah et al. 2008; Rudershausen et al. 2008*b*; Diamond and Campbell 2009; Sumpton et al. 2010). More favorable release conditions of black sea bass in this study paralleled greater rates of survival: black sea bass that swam down had 89% survival and fish that floated survived in 16% of cases. Thus, our study supports the conclusion that submergence after release with no hook trauma is an efficient and reasonably accurate method of inferring post-release outcome.

In conclusion, the use of SCUBA to tag black sea bass on the sea floor provided us with a powerful method to establish a group of control fish by which the discard survival of a physoclistous species with barotrauma and hook trauma could be estimated. Condition-specific survival estimates from tagging allowed us to estimate discard survival across a variety of gears and depths where this species is captured in commercial and recreational fisheries. These estimates of discard survival were lower than the assumed rates for hook and line (93%) and traps (≥95%) used in the most recent US South Atlantic assessment (SEDAR 2011). Future research should consider development of an adequate control to ensure more accurate estimates of discard survival in other managed reef fishes subject to gear- or pressure-related trauma. Additionally, we echo Davis' (2002, 2007) recommendations and urge researchers to record appropriate release condition variables when conducting discard survival studies to determine if release condition can be used as proxies for discard survival.

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