Abstract—The effects of barotrauma and other capture-related factors on the discard mortality of black sea bass (*Centropristis striata*) are poorly understood. The objective of this study was to estimate the discard mortality rate for black sea bass in the winter deepwater recreational fishery off New Jersey and to evaluate if swim bladder venting can reduce discard mortality. A total of 1823 fish were sampled at multiple depths (45, 58, and 67 m) from November 2016 through March 2017. To estimate discard mortality at a depth of 45 m, 96 individuals were tagged with acoustic transmitters and monitored with acoustic receivers. The majority (95%) of fish captured across all depths exhibited effects of barotrauma, which were more prevalent at greater depths. Results from longitudinal survival analyses indicate that venting was the most significant predictor of mortality at a depth of 45 m, with the estimated mean discard mortality rate being lower for vented (20%) than non-vented (49%) fish. Fight time had the largest statistical influence on the mortality of non-vented fish, whereas longer fight times (>54 s) resulted in higher mortality at a depth of 45 m. Discard mortality may have been higher at greater depths, but venting and other recommended practices can mitigate mortality at all depths sampled.

Discard mortality of black sea bass (*Centropristis striata*) in a deepwater recreational fishery off New Jersey: role of swim bladder venting in reducing mortality

Douglas R. Zemeckis (contact author)[1]
Jeff Kneebone[2]
Connor W. Capizzano[2,3]
Eleanor A. Bochenek[4]

William S. Hoffman[5]
Thomas M. Grothues[4]
John W. Mandelman[2]
Olaf P. Jensen[4]

Email address for contact author: zemeckis@njaes.rutgers.edu

[1] Department of Agriculture and Natural Resources
New Jersey Agricultural Experiment Station
Rutgers University
1623 Whitesville Road
Toms River, New Jersey 08755

[2] Anderson Cabot Center for Ocean Life
New England Aquarium
1 Central Wharf
Boston, Massachusetts 02110

[3] School for the Environment
University of Massachusetts Boston
100 William T. Morrissey Boulevard
Boston, Massachusetts 02125

[4] Department of Marine and Coastal Sciences
Rutgers University
71 Dudley Road
New Brunswick, New Jersey 08901

[5] Annisquam River Marine Fisheries Research
Field Station
Massachusetts Division of Marine Fisheries
30 Emerson Avenue
Gloucester, Massachusetts 01930

Black sea bass (*Centropristis striata*) support valuable commercial and recreational fisheries in the United States along the East Coast and in the Gulf of Mexico (NMFS, 2018). In the northern stock area (i.e., Cape Hatteras, North Carolina, to Canada), the recreational fishery is frequently responsible for a significant proportion of the total catch (e.g., 61% of the total 2015 catch; NEFSC, 2017) over a wide range of environmental conditions, habitats, and depths. These diverse recreational fisheries for black sea bass are governed by a suite of regulatory measures (e.g., minimum size limits, daily retention limits, and seasonal closures) in both state and federal waters along the East Coast of the United States (ASMFC[1]).

The discard rate of black sea bass in U.S. recreational fisheries is frequently high, with 33–56% of all captured fish being discarded annually from 2010 through 2015 (NEFSC, 2017). Discard rates vary by state and region in response to regulatory measures, "high-grading" practices, or angler catch-and-release conservation ethics. The latest stock assessments and fishery management plans for black sea bass assume a 15% discard mortality rate for the coast-wide, year-round recreational fishery (NEFSC, 2017). However, published estimates of the discard mortality rate for this

---

[1] ASMFC (Atlantic States Marine Fisheries Commission). 2017. 2017 Review of the

species vary considerably by region and depth of capture (e.g., 4.7–39.0%), with an increase in discard mortality evident at greater capture depths (Bugley and Shepherd, 1991; Collins et al., 1999; Rudershausen et al., 2014).

As a physoclistous fish species, black sea bass often suffer from barotrauma when captured in deepwater (>35 m) recreational fisheries (Collins et al., 1999; Davis, 2002). Typical barotrauma effects experienced by physoclists are species-specific (Jarvis and Lowe, 2008; Hannah et al., 2014) but can include swim bladder expansion or rupture, exopthalmia, and stomach eversion (i.e., prolapse). Previous studies have demonstrated that even minor barotrauma can impair postrelease behavior, reduce submergence success, and result in high rates of discard mortality in many popular recreational species (e.g., Sauls, 2014; Curtis et al., 2015), including in black sea bass (Collins et al., 1999; Rudershausen et al., 2014). Fortunately, a growing body of evidence indicates that discard mortality can often be reduced by implementing barotrauma relief measures, such as swim bladder venting, or by using descending (i.e., release) devices to release fish at depth as opposed to at the sea surface (Drumhiller et al., 2014; Pulver, 2017; Runde and Buckel, 2018). Although the efficacy of venting and descending devices in mitigating mortality is fishery- and species-specific (Wilde, 2009; Curtis et al., 2015; Eberts et al., 2018), some evidence indicates that swim bladder venting is preferred and more likely to be practiced by recreational anglers because of its low cost and rapid application (Crandall et al., 2018).

Most of the recreational catch (75%) and discards (82%) in the northern stock of black sea bass were estimated to have occurred within state waters (i.e., <5.6 km, or 3 nautical miles, from shore) from spring through early fall during 2011–2015 (NEFSC, 2017). Popular recreational fisheries in the northeastern United States also target or catch black sea bass as bycatch in federal waters from the late fall through early spring. These fisheries predominantly occur at greater depths (>35 m), while black sea bass are carrying out their winter inshore–offshore seasonal migration (Moser and Shepherd, 2009). Although these deepwater fisheries account for a relatively small and uncertain proportion of total recreational catch of black sea bass (NEFSC, 2017), they provide valuable fishing opportunities for recreational fishermen during a season when relatively few species are available to target off the northeastern United States. Anecdotal reports suggest that many black sea bass captured in these deepwater fisheries experience moderate to severe barotrauma, but barotrauma relief measures (e.g., swim bladder venting) are neither required nor commonly practiced voluntarily. Furthermore, the extent to which environmental (e.g., cold water and air temperatures) and ecosystem (e.g., predator species and abundance) conditions influence black sea bass discard mortality during the winter in recreational fisheries off New Jersey is unknown.

Results of recent studies indicate that discard mortality rates in recreational fisheries are influenced by numerous biological, environmental, and technical factors (e.g., Capizzano et al., 2016, 2019; Weltersbach et al., 2019).

Therefore, fishery- or region-specific estimates of discard mortality and recommendations for anglers for best practices in catch and release of black sea bass are required to provide the information needed for stock assessments, fishery management, and conservation efforts. The objective of this study was to estimate the discard mortality rate for black sea bass captured in the winter deepwater recreational fishery off New Jersey and to evaluate if swim bladder venting can reduce discard mortality.
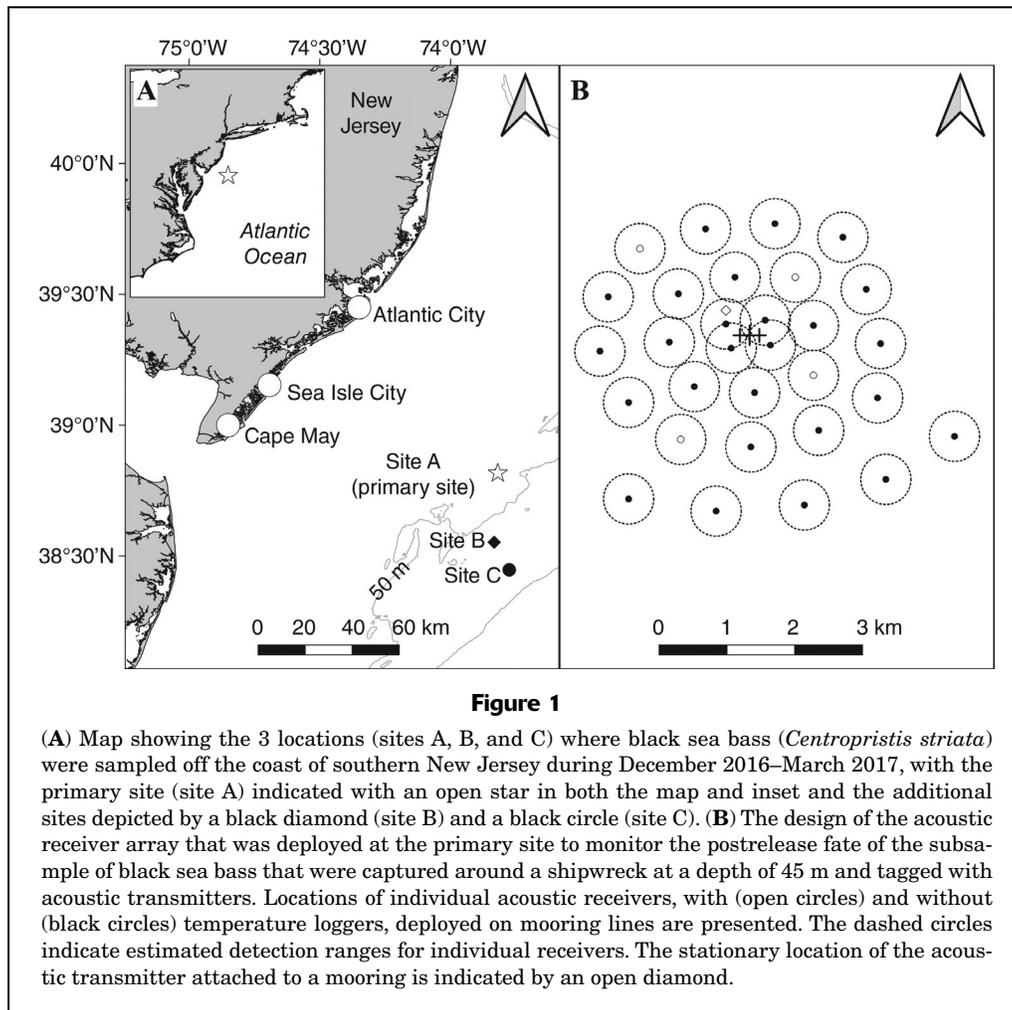
Materials and methods

Study sites

Black sea bass were sampled at 3 deepwater sites off the coast of southern New Jersey from December 2016 through March 2017 (Fig. 1A). The primary study site was a shipwreck (site A) located ~85 km southeast of Sea Isle City, New Jersey, at a depth of 45 m and sampled from December 2016 through February 2017. At this location, consistently high rates of catch of black sea bass are produced at a depth range that is representative of common offshore fishing grounds for this species. To investigate how the condition of captured fish and discard mortality might vary by capture depth, sampling was conducted during February and March 2017 at 2 additional sites where the depths were 58 m (site B) and 67 m (site C), respectively.

Sampling

Prior to any sampling, an online survey of recreational black sea bass anglers and captains of vessels in this fishery was conducted during October and November 2016 to determine the reel type (e.g., conventional, spinning, or electric), tackle (e.g., line type and strength and hook type and size), and rigging techniques (e.g., leader material, length, and configuration) most commonly used in the winter recreational offshore fishery for black sea bass off New Jersey. This survey was primarily distributed through online message boards for recreational anglers. On the basis of results of this survey (number of respondents: 282), we chose standardized terminal tackle rigs for use on all tagging trips. These rigs consisted of a high-low rig (i.e., lead sinker at the bottom with 2 hooks attached above through dropper loops) made with 22.7-kg monofilament leader material and two 5/0-size octopus hooks (model 92553-BN, O. Mustad and Son[2], Gjøvik, Norway). The volunteer anglers were allowed to use their own rods and reels to represent the variety used by anglers under typical conditions. The retrieve (i.e., gear) ratios of all reels were recorded, ranged from 2.5:1.0 to 7.1:1.0, and were classified broadly as *low speed* (reel retrieve ratio <5.0:1.0) or *high speed* (reel retrieve ratio >5.0:1.0).

Figure 1

(**A**) Map showing the 3 locations (sites A, B, and C) where black sea bass (*Centropristis striata*) were sampled off the coast of southern New Jersey during December 2016–March 2017, with the primary site (site A) indicated with an open star in both the map and inset and the additional sites depicted by a black diamond (site B) and a black circle (site C). (**B**) The design of the acoustic receiver array that was deployed at the primary site to monitor the postrelease fate of the subsample of black sea bass that were captured around a shipwreck at a depth of 45 m and tagged with acoustic transmitters. Locations of individual acoustic receivers, with (open circles) and without (black circles) temperature loggers, deployed on mooring lines are presented. The dashed circles indicate estimated detection ranges for individual receivers. The stationary location of the acoustic transmitter attached to a mooring is indicated by an open diamond.

The sampling of black sea bass occurred during for-hire charters aboard the head boats F/V *Susan Hudson* (vessel length: 17 m) from Sea Isle City, New Jersey, and F/V *Porgy IV* (vessel length: 24 m) from Cape May, New Jersey. Each sampling trip had 6–14 volunteer anglers and up to 4 scientific personnel. Prior to starting fishing activity, each volunteer angler was required to complete a questionnaire that quantified their experience level with respect to saltwater fishing in deep water (depths >35 m). For all fishing activities, volunteer anglers were provided with the standardized terminal tackle rig, the same bait (Atlantic surfclam, *Spisula solidissima*), and a lead sinker (284–567 g) appropriately sized for the sea conditions, and they were allowed to determine how best to fish, handle, and unhook their catch to promote authentic scenarios. For each captured black sea bass, a series of technical and biological variables that describe the capture event were recorded (Table 1). Each volunteer angler was provided a stopwatch to record fight time, unhooking time, and handling time.

Anecdotal reports from anglers have suggested that the inability to submerge due to barotrauma is a major contributor to discard mortality. Previous research has indicated that swim bladder venting can reduce the rate of discard mortality for black sea bass captured at depths of 42–55 m off South Carolina (Collins et al., 1999). Therefore, to examine the efficacy of swim bladder venting for reducing discard mortality of black sea bass, a subset of fish was vented by using a Ventafish VF-1 Fish Venting Tool (Big Pond Products LLC, Tallahassee, FL) with a 16-gauge replaceable needle and 45° beveled front end. To standardize the methods, all fish were vented by a single trained scientist by placing the fish flat on a measuring board and inserting the needle into the swim bladder behind the pectoral fin following directions provided by the manufacturer. This approach was taken to examine the potential benefit of proper venting technique and to avoid potential bias that may occur from improper venting (Wilde, 2009).

Tagging procedure and postrelease fate monitoring

To monitor postrelease fate, a subsample of 96 black sea bass captured at site A (depth: 45 m) were externally tagged through the dorsal musculature with 69-kHz pressure-sensing VEMCO acoustic transmitters equipped

Table 1

Description of the technical, biological, environmental, and physical capture-related variables recorded for each captured black sea bass (*Centropristis striata*). The sampling of black sea bass occurred during for-hire charters operating from Sea Isle City and Cape May, New Jersey, between December 2016 and March 2017. Exopthalmia is an effect of barotrauma.
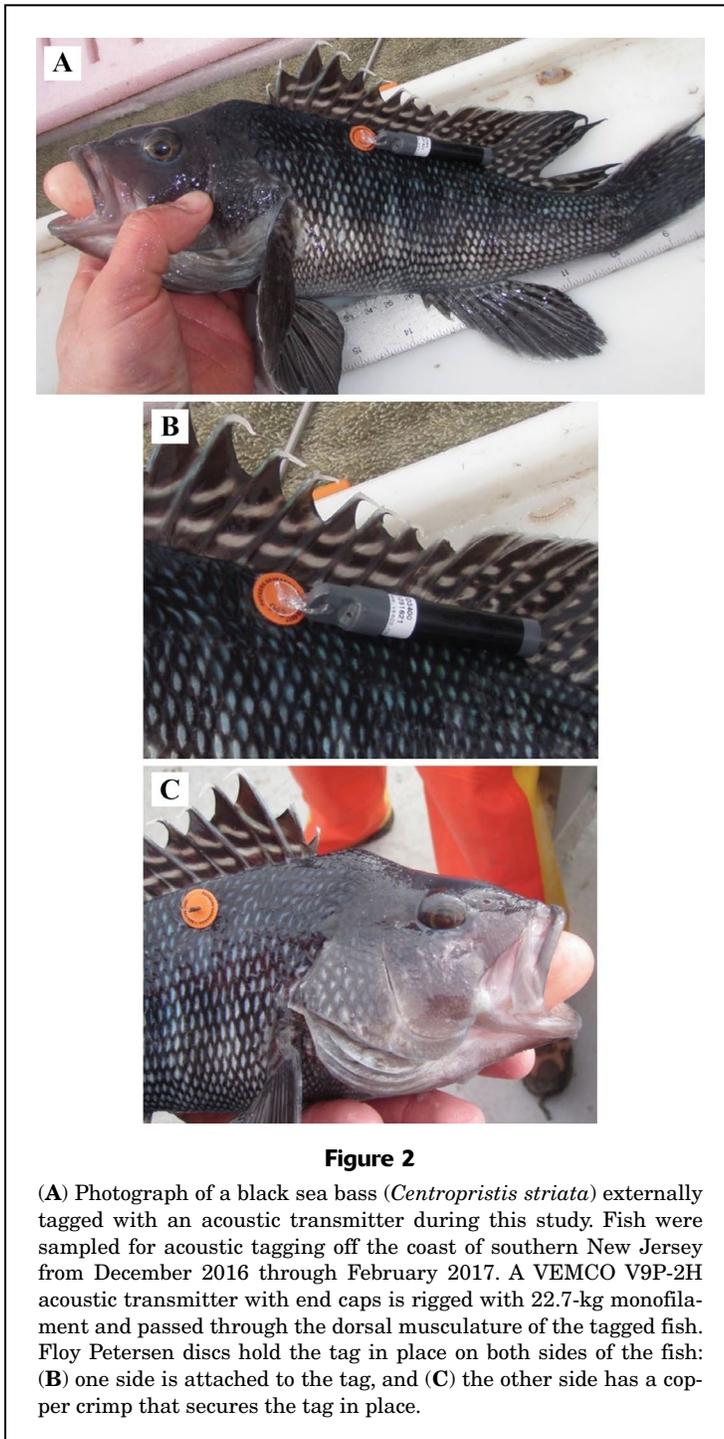
Variable (unit)	Description
Technical	
Capture depth (m)	Water depth at the location of capture
Angler experience	Angler experience score as classified by questionnaire (i.e., experienced or inexperienced)
Fight time (s)	Elapsed time from when a fish was hooked to when it reached the surface
Unhooking time (s)	Elapsed time from surfacing until the fish was unhooked
Handling time (s)	Elapsed time from surfacing until fish was released (time out of water)
Hook location	Mouth; body (foul hooked)
Hook removal method	Angler hand; mate hand
Biological	
Total length (mm)	Length from the tip of the snout to the tip of the center of the tail
Release behavior	Floating; swimming down; erratic swimming; sinking
Environmental	
Air temperature (°C)	On deck temperature at the time of capture
Surface temperature (°C)	Water temperature at the surface
Bottom temperature (°C)	Water temperature at the bottom or at the wreck
Delta temperature (°C)	Difference between surface and bottom water temperatures
Physical	
Injury	Present (1, >2 cm in length); absent (0)
Exopthalmia	Present (1); absent (0)
Stomach eversion	None (0); in mouth (1); protruding from mouth (2); ruptured (3)

with end caps (model V9P-2H, VEMCO, Bedford, Canada; dimensions: 29 mm long with 9-mm diameter; battery life: 673 d; pressure sensor maximum depth: 204 m; sensor resolution: 0.9 m; sensor accuracy: ±10 m). Transmitters were affixed to each fish by attaching a short piece of 22.7-kg monofilament to the transmitter's endcap and passing the monofilament through the dorsal musculature with a hypodermic needle. The transmitter was then secured in place by 2 Floy Petersen discs (Floy Tag Inc., Seattle, WA; 12.7-mm diameter) positioned on each side of the body (Fig. 2). Prior to at-sea sampling, a holding tank study was performed on captive black sea bass; this study confirmed that this attachment method resulted in no tag shedding or tagging-induced mortality over a 62-d period. Transmitters were programmed with a stepwise series of nominal transmission delay (120 s for 0–15 d; 300 s for 15–673 d). An equal number of vented and non-vented fish were tagged with acoustic transmitters (number of samples [n]=48, per treatment), and efforts were made to vent fish over all observed lengths and in an equal ratio across representative fishing conditions.

An array of 30 VEMCO VR2W 69-kHz acoustic receivers was strategically deployed around the shipwreck at site A to monitor the movements of black sea bass tagged with acoustic transmitters (Fig. 1B). To evaluate receiver detection range, a single V9P-2H transmitter was deployed on the bottom at a fixed location near the center of the array from January through March 2017. Analysis of detection data from this transmitter estimated the mean detection range (i.e., 50% probability of detection) to be 300 m (Winton et al., 2018). Twenty-five receivers were deployed for 119 d (28 November 2016–27 March 2017), and an additional 5 receivers were deployed for 69 d (17 January 2017–27 March 2017) along the southern extent of the array to better monitor fish emigration. HOBO Pendant temperature loggers (Onset Computer Co., Bourne, MA) were placed at the surface and bottom of the mooring lines of 4 receivers (Fig. 1B) and were programmed to record water temperature every 5 min (Table 1). Receivers were downloaded and cleaned every 30–45 d. Three receivers were lost during the study period.

To identify detection patterns indicative of a dead fish (i.e., continuous presence on the seafloor; see Yergey et al., 2012, and Capizzano et al., 2016), detection data were collected for 2 black sea bass that were intentionally sacrificed, tagged with acoustic transmitters, and released at the seafloor by using a descending device to minimize the risk of predation on the carcasses. These fish served as negative controls, and their detection histories were used to help identify mortality events in fish tagged with acoustic transmitters. In contrast, movement data obtained for 7 acoustically tagged black sea bass that were confirmed to be alive, either by acoustic detection in the Atlantic Cooperative Telemetry Network (n=4) or fishery-dependent recapture (n=3), were used as positive controls to distinguish behavior of black sea bass known to be alive.

Figure 2

(**A**) Photograph of a black sea bass (*Centropristis striata*) externally tagged with an acoustic transmitter during this study. Fish were sampled for acoustic tagging off the coast of southern New Jersey from December 2016 through February 2017. A VEMCO V9P-2H acoustic transmitter with end caps is rigged with 22.7-kg monofilament and passed through the dorsal musculature of the tagged fish. Floy Petersen discs hold the tag in place on both sides of the fish: (**B**) one side is attached to the tag, and (**C**) the other side has a copper crimp that secures the tag in place.

Data analysis

A suite of models was employed to evaluate the effect of capture-related variables on discard mortality of black sea bass. Model selection procedures for identifying the most parsimonious model for each analysis in this study followed a stepwise forward selection procedure based on changes in the Akaike information criterion corrected for small sample sizes (ΔAICc) of 3 units or more (Burnham and Anderson, 2002) according to Benoît et al. (2010). Given the potential effect of individual angler behavior on results, an *angler* covariate was included as a random effect in all mixed-effect models to account for within-cluster correlation (e.g., Benoît et al., 2010; Knotek et al., 2018). All statistical analyses were performed in R (vers. 3.5.2; R Core Team, 2018), and statistical significance was accepted at a level of $P<0.05$.

Capture characteristics To investigate the relationship between fight time and several variables, including fish total length (TL), capture depth, capture as part of an event referred to as a *double header* (i.e., 2 fish captured simultaneously, 1 fish on each hook), and reel ratio (i.e., high or low speed reels), a generalized additive mixed-effect model with an inverse link function was performed by using the R package mgcv, vers. 1.8-26 (Wood, 2011). A mixed-effect logistic regression was also employed to evaluate the relationship between release behavior and several capture-related variables, including capture depth, TL, physical injury, presence of exopthalmia, presence of stomach eversion, and venting treatment.

Fate assessment The fate (i.e., alive or dead) of individual black sea bass tagged with acoustic transmitters was assessed by comparing vertical and horizontal movements against those of positive and negative controls. Prior to analysis, all transmitter data were initially vetted for false detections by using the false detection analyzer tool in VEMCO's User Environment (vers. 2.2.2) and irrational detection data that coincided with potential transmitter failures. Given the effect of misclassified mortality events in longitudinal survival analyses (described later), we employed a 3-step approach to determine the fate of individual fish. Step 1 involved the use of a discriminant function analysis, which creates a function capable of classifying individuals of unknown fate into groups based on metrics from individuals with known fates (White and Ruttenberg, 2007) by using solely acoustic detection data. A discriminant function was created by using gross movement metrics from positive and negative controls, specifically maximum depth variance, minimum depth, and the proportion of total depth observations that were shallower than an individual's mean overall observed depth minus the mean depth variance of the dead control fish. The discriminant function was executed by using the MASS package (vers. 7.3-45; Venables and Ripley, 2002) in R and resulted in a fate assignment for each fish.

Step 2 included the application of a variance test on depth observations recorded at defined intervals throughout the

detection history of each acoustically tagged fish (Capiz-
zano et al., 2016, 2019). Only intervals with at least
10 observations were included in the analysis. To account
for the effect of tide height on individual depth observa-
tions, the tidal cycle at site A was estimated and removed
from each transmitter's depth record by using package oce
(vers. 09-21; Kelley and Richards, 2017). The variance of
tide-corrected depth observations in each time interval
was individually compared with that of the negative con-
trols for each fish by using a 1-tailed t-test of the absolute
difference from the median (modified Browne–Forsythe
test for homogeneity of population variance; Ott and Long-
necker, 2010), hereafter referred to as the *depth-variance
test*. Because of the occurrence of off-bottom movements
in black sea bass, when the depth variance of a tagged
fish was significantly different ($P<0.05$) from the negative
controls during one or more time intervals, the fish was
classified as being alive.

Following steps 1 and 2, all fish that were detected for
>2 d and had the same fate predicted by both the dis-
criminant analysis (i.e., step 1) and depth-variance test
(i.e., step 2) ($n=50$) were assigned the appropriate fate.
The final fate of the remaining detected fish ($n=44$),
because of the brevity of their monitoring period (i.e., the
lack of critical movement data for the depth-variance
test) or the discrepancy between the discriminant anal-
ysis and depth-variance results, was determined in step
3 by using 1) a semiquantitative assessment of the hori-
zontal and vertical movement patterns of each fish that
placed particular emphasis on the comparison of their
movements to those evident in both positive and nega-
tive controls and 2) an analysis of each fish's horizontal
trajectory in relation to surface and bottom currents esti-
mated at the study site by the Regional Ocean Modeling
System (ROMS, vers. 3.6; Allen et al., 2003; ROMS/TOMS
Group, 2013).

Briefly, if a fish's general pattern of movement was char-
acterized by bottom-oriented behavior with some vertical
movements and nonlinear horizontal emigration from the
receiver array, it was considered to be alive. Fish were con-
sidered dead if they consistently remained at depth (i.e., on
the seafloor) and made horizontal movements restricted to
a straight line in the direction of the prevailing bottom
current predicted by the ROMS model. In some instances,
transmission data indicate more rapid horizontal move-
ments and more frequent vertical movements of greater
magnitude (i.e., 15–20 m off bottom) than were apparent
in positive controls. These instances were considered pre-
dation events, a characterization that is consistent with
reports from industry collaborators and with observations
recorded during tagging that some fish are consumed by
predators while being reeled up to the surface or while
resubmerging postrelease. All fish with events identified
as predations were included in the survival analysis as
dead fish.

Longitudinal analysis   Because the continuous acoustic
monitoring of tagged black sea bass identified the time
when fish either died or were last observed to be alive

(i.e., longitudinal data), traditional survival analyses
were used to address 2 objectives following procedures
outlined by Knotek et al. (2018). The first objective was
to evaluate the suitability of recorded capture-related
variables (i.e., covariates) for predicting survival and
then identify a parsimonious subset of those covariates
that best predict survival. The second objective was to
use this subset of covariates to assess whether potential
models were capable of describing the survival function
(i.e., cumulative probability of survivorship over time;
Cox and Oakes, 1984) and estimating discard mortality
of tagged black sea bass.

Evaluation of relevant capture-related factors for survival   A
combination of nonparametric and semiparametric lon-
gitudinal survival analyses were used to address the
first objective. First, the empirical and nonparametric
Kaplan–Meier (KM) estimator was used to visually
explore the individual effect of capture-related covari-
ates (Table 1) on the survival function (Cox and Oakes,
1984). For instances in which a categorical covariate
had more than 2 groupings, and thus survival functions,
the Peto–Peto modification of the Gehan–Wilcoxon log-
rank test was used to evaluate if 2 or more survival
functions were statistically different (Harrington and
Fleming, 1982).

By reviewing the output of KM estimator plots and log-
rank tests, 6 sensible covariates were selected a priori as
variables that potentially influence discard mortality in
black sea bass: fight time, handling time, TL, presence
of physical injury, temperature differential between sur-
face and bottom waters, and venting treatment. All other
covariates that did not produce meaningful differences
in their KM survival functions and log-rank tests were
not considered and were dropped from the analysis. The
release behavior covariate was dropped because of insuf-
ficient sample size among groups and its strong correla-
tion with the venting treatment variable. Preliminary
results from KM estimators and log-rank tests also sup-
port the categorization of various covariates, which was
accomplished by either binning all continuous covariates
of interest at their median value or combining groups in
categorical covariates to produce meaningful associations
(e.g., angler experience scores into experience categories).
Such categorizations resulted in the addition of a 7th
covariate, the general season of capture (i.e., astronomical
autumn and winter).

Despite the KM estimator's ability to track the pro-
portion of individuals considered to be alive at each time
interval in the absence of censored observations, it pro-
vides a univariate analysis. Therefore, to objectively
evaluate the additive effect of multiple covariates as pre-
dictors of survival, a mixed-effect Cox proportional haz-
ards model (CPHM) was used to address the first objective
(Cox, 1972; Therneau and Grambsch, 2000). A suite of
CPHMs that incorporate all 7 covariates was constructed,
and the CPHMs were compared by using a stepwise for-
ward selection procedure with ΔAICc. Covariates that
ultimately best fit the data were retained and used in the

second objective to both describe the survival function and estimate discard mortality.

Predicting discard mortality with relevant covariates Regardless of their ability to fit the data, nonparametric and semiparametric models cannot be used to parse out different mortality sources (e.g., capture and handling mortality and postrelease mortality) or provide mechanistic interpretations of survivorship patterns over time (Benoît et al., 2015). Therefore, the parametric modeling approach developed by Benoît et al. (2015) was used because of its ability to explicitly account for these types of mortality and to provide estimates for each. The survival function for this model, the probability of surviving to time $S(t)$, is expressed with the following equation:

$$S(t) = \tau \times \left\{ \pi \times e^{-[\alpha \times t]^\gamma} + \left(1 - \pi\right) \right\},$$

where τ = the probability of surviving capture and handling;

π = the probability that an individual was adversely affected by the fishing event postrelease; and

α and γ = the scale and shape parameters, respectively, of an underlying Weibull distribution that determines the mortality patterns over time for adversely affected individuals.

From this equation, we can understand that when t is 0, $S(t)$ is equal to τ. Therefore, as t increases to ∞, the expression $\tau \times \pi \times e^{-[\alpha \times t]^\gamma}$ decreases to 0 (i.e., all affected fish die) and $S(t)$ becomes τ(1–π) (i.e., only unaffected individuals remain alive). Additional details and justification of this model, including the use of maximum likelihood methods for fitting the data to the model, are provided in Benoît

et al. (2012, 2015), and examples of this equation can be found in Capizzano et al. (2019).

After determining the basic model and appropriate terms to include, model variants of this equation were developed and fit with covariates of interest to address the second objective. The influence of covariates from the first objective that may affect survival are often introduced on τ and π terms in the model (e.g., Capizzano et al., 2016, 2019). Three model variants of this equation therefore were fit to the data (Table 2) and visually assessed by superimposing predicted survival functions on the KM estimates and 95% confidence intervals (CIs). Relative fit between model variants and selected covariates was quantified and compared with the stepwise forward selection procedure by using ΔAICc as previously described.

Evaluating relevant covariates for unvented subsample The nonparametric KM estimator and semiparametric CPHM survival analyses were also applied to data for unvented fish in the subsample of fish tagged with acoustic transmitters to examine the suitability of other covariates for predicting survival. Six sensible covariates previously included in the mixed-effect CPHM selection procedure were selected a priori and with evidence from KM estimators: fight time, handling time, TL, presence of physical injury, temperature differential between bottom and surface waters, and general season of capture (i.e., astronomical fall and winter). The angler covariate was included as a random effect. Despite the strengths of the parametric Weibull mixture distribution modeling approach described earlier, only the mixed-effect CPHM modeling procedure was used because sample sizes of fish were halved when examining only unvented fish.

Table 2

Three variants of the survival model developed by Benoît et al. (2015) to analyze the survivorship of black sea bass (*Centropristis striata*) over time and fit to data from sampling conducted off southern New Jersey between December 2016 and February 2017. Assumptions for parameters of the equation used to express the survival function (see the "Data analysis" section), specifically the probability of surviving capture and handling (τ) and the probability of being adversely affected by the fishing event postrelease (π), were used to define the 3 competing model variants. X=the design matrix for the covariates; β=the vector of parameters for the effect of the covariates.

Variant	Parameters	Description
1	$\tau = \left[1 + e^{\left(-X'\beta_1\right)}\right]^{-1}$ $\pi = \left[1 + e^{\left(-X'\beta_2\right)}\right]^{-1}$	Covariate effects on the probability of surviving capture and handling and the probability of being adversely affected by the fishing event postrelease
2	$\pi = \left[1 + e^{\left(-X'\beta_3\right)}\right]^{-1}$	Covariate effect on only the probability of being adversely affected by the fishing event postrelease
3	$\tau = \left[1 + e^{\left(-X'\beta_4\right)}\right]^{-1}$	Covariate effect on only the probability of surviving capture and handling

Results

Capture characteristics

Fifty volunteer anglers captured 1823 black sea bass (size range: 136–612 mm TL) (Table 3). Given the federal minimum landing size of 317.5 mm TL in 2017, 40% of the sampled fish would have been smaller than the legal limit. Forty-three anglers (86%) were classified as being *experienced* on the basis of their answers to our questionnaire and were responsible for the capture of 92% of the sampled fish. Capture-related variables were recorded for all fish with the exception of 110 fish that were retained for an aging experiment and had no venting status or release behavior recorded. A total of 957 fish had their swim bladder vented before release; 756 fish were released unvented. There were 321 capture events classified as a double header. The majority of fish (92%) were hooked in the mouth, but some fish were also foul-hooked in various locations of the body.

A total of 304 black sea bass (17%) incurred injuries (i.e., wounds >2 cm), mostly as a result of hooking trauma or the hook removal process. Twelve individuals (<1%) were dead upon landing, with most of them (*n*=8) having been bitten in half following predation by other fish. The vast majority of captured black sea bass (95%) exhibited effects of barotrauma, with a stomach eversion score of 2 (i.e., stomach protruding from the mouth cavity) present in 68% of all captured fish. Barotrauma effects were generally more prevalent in fish coming from greater depths, particularly exopthalmia, which was most prevalent at the deepest capture depth (Fig. 3).
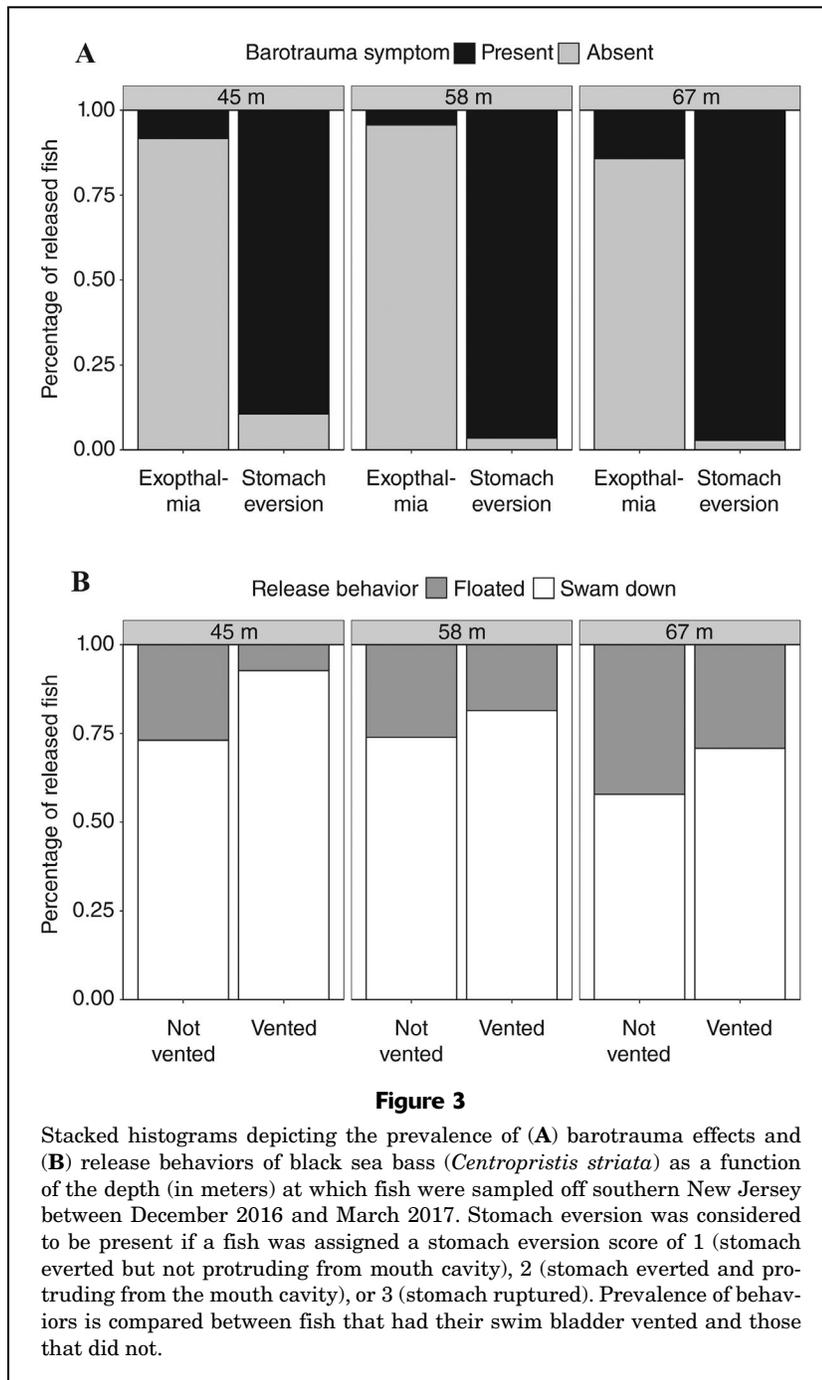
Released black sea bass exhibited 4 behaviors, with the vast majority either swimming down (74%) or floating (25%). Only a small number of fish swam erratically (<1%) or sank (<1%). The prevalence of floating behavior was greater in fish captured at greater depths (Fig. 3).

Strong evidence from this study indicates that fight time increased in response to TL, capture depth, capture as part of a double header, and reel ratio (Table 4). Depth was the most influential factor affecting fight time, with fish captured at the deepest depth (67 m) experiencing the longest fight times. At each depth, interpolation of mean fight time indicates that fish >491 mm TL fought for longer than average durations. The results of a mixed-effect logistic regression indicate that TL, capture depth, venting, and the presence of exopthalmia weakly influenced release behavior, with fish having a lower probability of swimming down if they were larger in size, not vented, caught at greater depths, and experienced exopthalmia (Table 4, Fig. 4).

Table 3

Summary of capture variables from observations for all 1823 sampled black sea bass (*Centropristis striata*), including those for the 96 fish that were tagged with acoustic transmitters. Black sea bass were sampled off southern New Jersey between December 2017 and March 2017 at 3 sites with varying depths of capture (45, 58, and 67 m). Two methods of hook removal were used: angler hand and mate hand. Mean values are provided with standard deviations (SDs) in parentheses. The federal legal size limit for capture of black sea bass was 317.5 mm TL in 2017. An asterisk (*) indicates that water temperatures were available only for the primary site, a shipwreck located ~85 km southeast of Sea Isle City, New Jersey.

Variable (unit)	Tagged fish		All observations	
	Range	Mean (SD)	Range	Mean (SD)
Total length (mm)	278–546	354 (57)	136–612	339 (70)
No. fish at legal vs. non-legal size	–	–	1089/722	–
45 m	64/32	–	199/359	–
58 m	–	–	405/47	–
67 m	–	–	485/316	–
Fight time (s)	17–225	56 (24)	12–251	78 (32)
45 m	17–225	56 (24)	12–225	55 (22)
58 m	–		32–240	80 (27)
67 m	–		35–251	94 (30)
Unhooking time (s)	2–52	15 (11)	10–215	17 (19)
Angler hand	2–49	15 (11)	1–215	18 (20)
Mate hand	3–52	15 (12)	2–173	17 (17)
Experienced anglers	2–52	14 (11)	1–189	17 (19)
Inexperienced anglers	13–36	29 (9)	2–215	19 (21)
Handling time (s)	80–326	164 (51)	13–575	142 (81)
Air temperature (°C)	5.9–15.1	10.7 (2.3)	4.7–17.4	13.9 (2.4)
Sea surface temperature (°C)	7.4–13.8	11.4 (2.1)	7.2–13.9*	12.4 (1.7)*
Bottom temperature (°C)	7.4–13.8	11.3 (2.0)	7.5–13.4*	12.2 (1.4)*
Delta temperature (°C)	−0.6–0.4	0.1 (0.3)	−0.3–0.5*	0.3 (0.3)*

Figure 3
Stacked histograms depicting the prevalence of (**A**) barotrauma effects and (**B**) release behaviors of black sea bass (*Centropristis striata*) as a function of the depth (in meters) at which fish were sampled off southern New Jersey between December 2016 and March 2017. Stomach eversion was considered to be present if a fish was assigned a stomach eversion score of 1 (stomach everted but not protruding from mouth cavity), 2 (stomach everted and protruding from the mouth cavity), or 3 (stomach ruptured). Prevalence of behaviors is compared between fish that had their swim bladder vented and those that did not.

Survivorship assessment

Acoustic detection data were obtained for 94 of the 96 tagged black sea bass. The 2 fish that were not detected by the array were floating after release and were among the smallest individuals to be tagged with acoustic transmitters (286–287 mm TL). Of the 94 detected fish, 61 survived the capture, handling, and release processes and 33 died after release. Of those fish considered to be alive, 60 emigrated from the receiver array during the monitoring period, and the single fish that was detected within the acoustic array on the last day of monitoring (3 March 2017) was later detected by a receiver array off Maryland, confirming its survival. Of the 33 mortalities, 9 (27%) were attributed to predation following resubmergence (i.e., as the animal descended toward the seafloor or after it reached the seafloor). All predation events occurred between 1.8 and 18.4 h (mean: 7.2 h [standard deviation (SD) 4.5]) postrelease. The remaining 24 mortalities were assumed to have occurred as a result of the fishing event and occurred 5.0–128.0 h (mean: 17.1 h [SD 26.7]) postrelease (95.8% of mortality occurred within 72 h).

When examining the entire subsample of black sea bass for which acoustic data are available ($n=94$), the effect of venting treatment covariate was the only significant predictor of survival (CPHM approach; ΔAIC: 4.84) that primarily influenced the probability that a fish was adversely affected by the fishing event postrelease (Weibull mixture distribution modeling approach; Table 5, model variant 2). Most of the mortality of black sea bass was estimated to have occurred postrelease (Table 6), with mean rates of discard mortality for non-vented fish (49%; 95% CI: 32–63%) nearly 2.5 times greater than the rates for vented fish (20%; 95% CI: 11–35%) (Fig. 5).

With respect to the non-vented black sea bass ($n=46$) in the subsample, a mixed-effect CPHM found that the fight time variable best predicted survival for unvented fish (ΔAICc: 7.27). The CPHM's hazard ratio indicates that fight time was positively associated with the event probability (i.e., increased fight times increase the chance of mortality; $P<0.05$). For example, when the median fight time value (54 s) was used as a cutoff to form 2 groups, non-vented black sea bass that experienced fight times >54 s were estimated to suffer roughly 74% mortality, a much higher rate than the 29% mortality estimated for fish with fight times ≤54 s (Fig. 6).

Discussion

Our results indicate that swim bladder venting, when done correctly, reduced the discard mortality rate for black sea bass by almost 30% following capture at a depth of 45 m.

Table 4

Results of forward model selection for the generalized additive mixed-effect model used to examine the relationship between the capture-related variables and fight time and for the mixed-effect logistic regression model that evaluated release behavior against a set of sensible covariates for all released black sea bass (*Centropristis striata*) (*n*=1594). Covariates that produced a reduction of 3 or more units in the Akaike information criterion corrected for small sample sizes (AICc) from the previous model were retained. Values for the change in AICc from the previous candidate model (ΔAICc) are provided. Data used in the models are from sampling of black sea bass conducted off southern New Jersey between December 2016 and March 2017. An asterisk (*) indicates the model that best fits the data. Exopthalmia is an effect of barotrauma. TL=total length; DH=double header, an event when 2 fish are captured simultaneously, 1 fish on each hook.

Model	Estimated df	Deviance explained (%)	AICc	ΔAICc
Fight time				
~ 1	47.32	49.91	15688.16	595.88
~ s(TL)	48.29	54.24	15531.77	439.49
~ s(TL) + depth	49.46	63.10	15150.16	57.88
~ s(TL) + depth + DH	50.64	64.04	15105.86	13.58
~ s(TL) + depth + DH+ reel gear*	51.52	64.30	15092.28	0.00
Release behavior				
~ 1	47.32	1.98	1832.16	95.28
~ Depth	48.29	2.90	1783.03	49.13
~ Depth + venting	49.46	4.97	1747.24	35.79
~ Depth + venting + TL	50.64	5.47	1740.04	7.20
~ Depth + venting + TL + exopthalmia*	51.52	5.75	1736.88	3.16
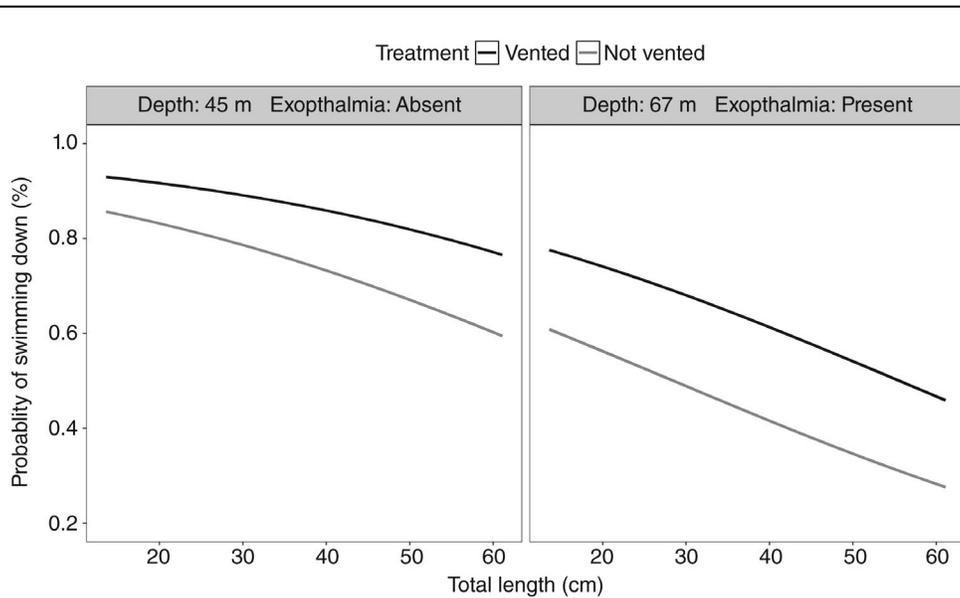
Figure 4

Probability that a released black sea bass (*Centropristis striata*) will actively swim down if it had its swim bladder vented (black line) or not vented (gray line), and how that probability varies by total length, depth of capture, and the presence of exopthalmia. Data used to model the probabilities came from fish sampled off southern New Jersey during December 2016–March 2017. For simplicity, 2 plots illustrate the overall submergence probability of fish with no exophthalmia captured at a shallow depth (45 m, left plot) in comparison to that of individuals with exophthalmia captured at a greater depth (67 m, right plot) by venting treatment and total length.

Table 5

Summary of results of model variant and covariate selection that used maximum likelihood and a forward selection procedure for the subsample of black sea bass (*Centropristis striata*) tagged with acoustic transmitters (*n*=96). Black sea bass were sampled off southern New Jersey at a depth of 45 m between December 2016 and February 2017. Values for the Akaike information criterion corrected for small sample sizes (AICc) and for the change in AICc from the previous candidate model (ΔAICc) are provided. An asterisk (*) denotes that the strongest evidence was for variant 2 of the model, which included the effect of venting covariate on the probability that a fish was adversely affected by the fishing event postrelease.

Run	Covariates	Variant	AICc	ΔAICc
1	~1	–	134.90	–
2*	~Venting	2	129.40	5.50
2	~Venting	1	132.52	2.38
2	~Venting	3	146.05	−11.15

These results are consistent with those from previous work that found that swim bladder venting reduced the discard mortality rate for black sea bass off South Carolina (Collins et al., 1999) and from a recent meta-analysis that found that swim bladder venting, as well as the use of descending devices, had positive effects and reduced discard mortality for fish of several species that experienced barotrauma (Eberts and Somers, 2017). Interestingly, the clear benefits of proper swim bladder venting presented herein are counter to previous assertions that this practice should be prohibited given the possibility that it may adversely affect the survival of fish captured from deep water (e.g., Wilde, 2009). Because of the detrimental
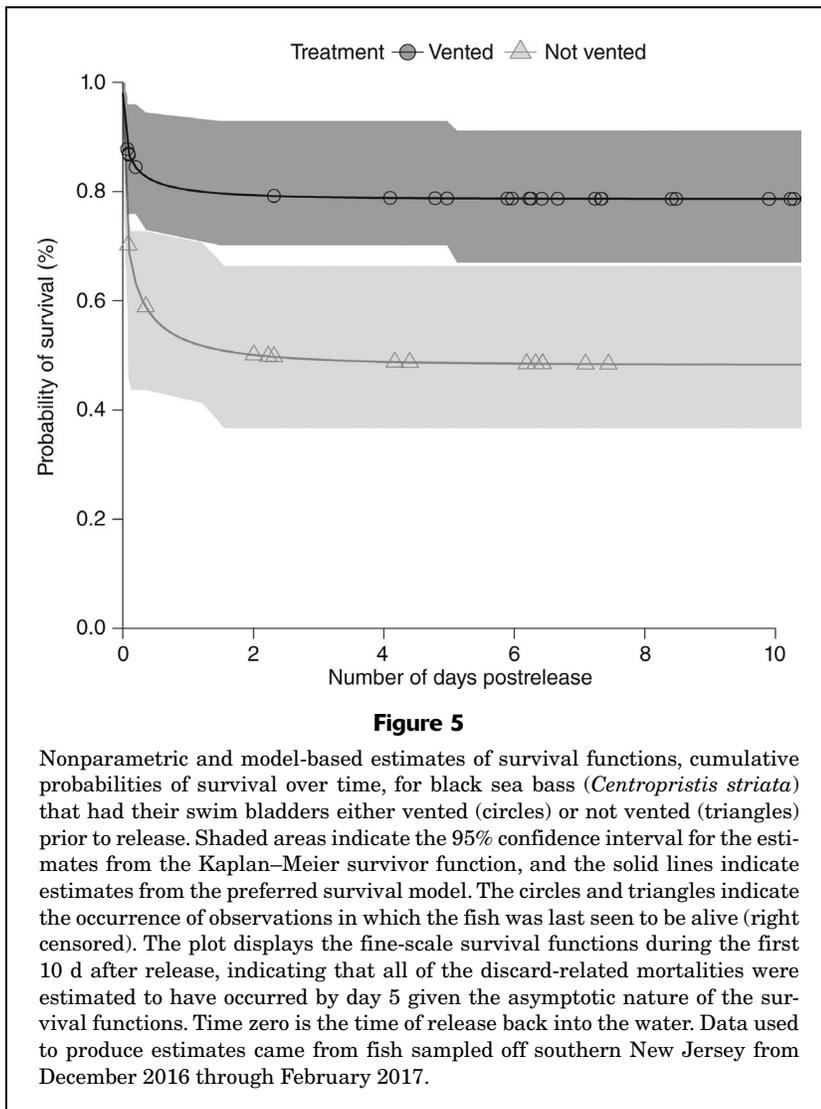
effects of improper venting technique (e.g., Scyphers et al., 2013; Brownscombe et al., 2017), the benefit of swim bladder venting for reducing discard mortality of black sea bass in deepwater recreational fisheries will not be fully realized without the extensive education and training of recreational anglers on proper venting techniques. Accordingly, future research should evaluate the relative benefits of swim bladder venting against those of using descending devices for reducing discard mortality of black sea bass in order to develop recommendations for the most appropriate catch-and-release procedures, particularly given that 40% of the fish sampled were below the minimum landing size and would have been discarded under typical fishery scenarios.

Our collaborations with industry stakeholders in New Jersey indicate that offshore anglers or crewmembers on for-hire vessels that target black sea bass do not commonly practice swim bladder venting. Therefore, the estimate of 49% for the discard mortality rate of non-vented fish is most representative of the contemporary winter deepwater fishery when it operates at a depth of 45 m off New Jersey. This estimate of discard mortality is higher than previous estimates generated for non-vented fish captured over a similar depth range off South Carolina (39% mortality at depths of 43–54 m; Collins et al., 1999). However, this discrepancy could be in part a result of the fact that Collins et al. (1999) monitored the postrelease fate of fish for only 24 h while they were in cages, where animals were shielded from predation. In contrast, our electronic tagging approach enabled accounting for mortality occurring because of postrelease predation by fish of other species and documentation of delayed mortality up to 128 h after release. It is also possible that differing estimates of discard mortality rate were influenced by varying environmental conditions (e.g., air or water temperatures) between our winter study off New Jersey and the study completed by Collins et al. (1999) off South Carolina.

Table 6

Sample sizes and estimates of key parameters for the analysis of survival data for black sea bass (*Centropristis striata*) that had their swim bladder vented after capture at a depth of 45 m off southern New Jersey between December 2016 and February 2017. The numbers of fish that died upon release (dead), died during capture and handling or immediately after release (left censored), and were last observed to be alive (right censored) are presented. Estimates of the capture and handling mortality rate $(1-\tau)$, the conditional postrelease mortality rate $(\tau\times\pi)$, and the total mortality rate associated with the fishing event (i.e., discard mortality; $1-\tau+\tau\times\pi$) are presented by treatment group, with 95% confidence intervals provided in parentheses.

	No. of samples				Fishing mortality rates		
Treatment	Total	Dead	Left	Right	Capture and handling	Postrelease	Total
Vented	48	9	1	38	0.017 (0.001–0.158)	0.203 (0.107–0.351)	0.219 (0.131–0.406)
Not vented	46	18	5	23	0.017 (0.001–0.158)	0.487 (0.319–0.633)	0.504 (0.362–0.662)

Figure 5

Nonparametric and model-based estimates of survival functions, cumulative probabilities of survival over time, for black sea bass (*Centropristis striata*) that had their swim bladders either vented (circles) or not vented (triangles) prior to release. Shaded areas indicate the 95% confidence interval for the estimates from the Kaplan–Meier survivor function, and the solid lines indicate estimates from the preferred survival model. The circles and triangles indicate the occurrence of observations in which the fish was last seen to be alive (right censored). The plot displays the fine-scale survival functions during the first 10 d after release, indicating that all of the discard-related mortalities were estimated to have occurred by day 5 given the asymptotic nature of the survival functions. Time zero is the time of release back into the water. Data used to produce estimates came from fish sampled off southern New Jersey from December 2016 through February 2017.

Postrelease predation had a noteworthy influence on the discard mortality rate for black sea bass, accounting for 27% of all documented mortality events. Results of previous research conducted off North Carolina indicates that predation of black sea bass during descent to the bottom may not greatly affect discard mortality (Rudershausen et al., 2014). However, on the basis of discussions with our industry collaborators and observations made during tagging, predation events can be common during the early part of the winter offshore fishing season off New Jersey (i.e., November and December) when predators, such as bluefish (*Pomatomus saltatrix*) and spiny dogfish (*Squalus acanthias*), are commonly present on the fishing grounds. Interestingly, no postrelease predation was observed for any acoustically tagged fish that was released after 21 December 2016, and no predation was observed during all trips to deeper fishing locations from mid-February through late-March of 2017. Therefore, predation on black sea bass by fish of other species both during capture and
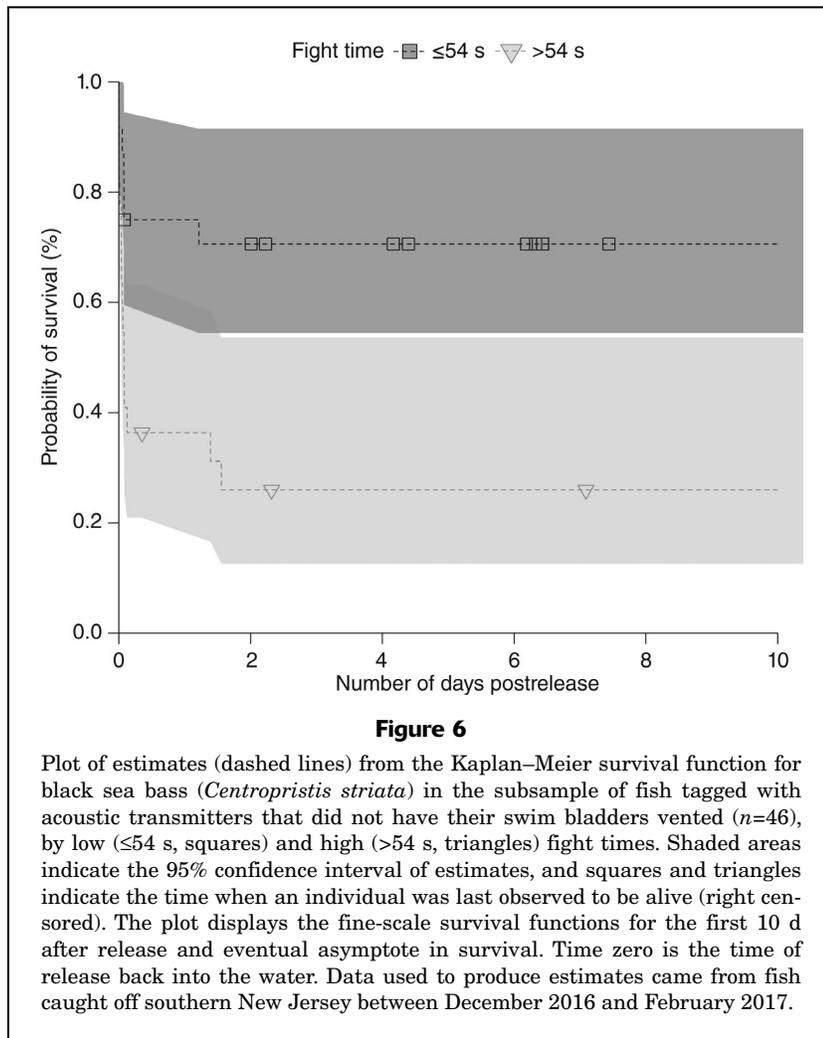
postrelease varied spatially and temporally, information that will be useful in consideration of fishery management options concerned with discards.

The practice of swim bladder venting was the single greatest predictor of discard mortality in the full subsample of fish tagged with acoustic transmitters, with unvented fish having lower submergence success than vented fish at all capture depths. Collectively, only 17% (2 out of 12) of the detected acoustically tagged fish that floated upon release ultimately survived, a rate that is consistent with the report by Rudershausen et al. (2014) that the inability to submerge did not result in 100% discard mortality. In addition, it is possible that the only 2 acoustically tagged fish not detected by any acoustic receiver experienced avian predation while floating at the sea surface. Avian predators, primarily herring (*Larus argentatus*) and great black-backed (*Larus marinus*) gulls, were abundant during the sampling trips during which these 2 fish were released, and these gulls were observed actively preying upon other released fish that did not have acoustic transmitters. Because the occurrence and prevalence of avian predation could not be fully accounted for during our study, actual discard mortality rates could be higher than those reported in this paper.

The latest stock assessments and fishery management plans for black sea bass assume a 15% discard mortality rate for the coast-wide, year-round black sea bass recreational fishery (NEFSC, 2017). Our results, as well as those of previous studies (e.g., Collins et al., 1999; Rudershausen et al., 2014), indicate that the discard mortality of black sea bass in deep waters is higher than the assumption that was applied in the last stock assessment. As a result, it is recommended that stock assessment scientists and fishery managers consider the higher discard mortality rates for deepwater fisheries in federal waters when quantifying total fishery removals and developing management measures. This is important for the winter offshore fishery because fishing effort and total catch during this season are not effectively monitored and estimates of discard mortality rates can factor heavily into different management options for recreational fisheries (e.g., the groundfish fishery in New England; Lee et al., 2017).

Our results add to the growing knowledge that capture depth has a large effect on discard mortality of black sea bass (e.g., Collins et al., 1999; Stephen and Harris, 2010; Rudershausen et al., 2014). For example, our estimate of the discard mortality rate for non-vented fish (49%) was

Figure 6

Plot of estimates (dashed lines) from the Kaplan–Meier survival function for black sea bass (*Centropristis striata*) in the subsample of fish tagged with acoustic transmitters that did not have their swim bladders vented (*n*=46), by low (≤54 s, squares) and high (>54 s, triangles) fight times. Shaded areas indicate the 95% confidence interval of estimates, and squares and triangles indicate the time when an individual was last observed to be alive (right censored). The plot displays the fine-scale survival functions for the first 10 d after release and eventual asymptote in survival. Time zero is the time of release back into the water. Data used to produce estimates came from fish caught off southern New Jersey between December 2016 and February 2017.

not found to be a significant predictor of discard mortality for black sea bass. The vast majority of individuals (83%) did not experience hook trauma following a capture event, and there was a low incidence (<1%) of deep or internal hooking in the esophagus, viscera, or gills. This low incidence of deep hooking may result from the use of a high-low terminal tackle rig with short leaders from the main line to each hook (i.e., dropper loops of 7.6–12.7 cm). As suggested by Capizzano et al. (2016), this configuration does not leave much opportunity for the fish to swallow the hook and therefore results in a high incidence of mouth hooking. The use of circle hooks, which have been reported to increase the incidence of mouth hooking in other fisheries (see the review by Cooke and Suski, 2004), may not offer an appreciable conservation benefit for black sea bass, given the already low incidence of deep hooking observed with the high-low tackle rig and octopus hooks used in this study.

The survivorship assessment used to infer fate of individual fish was complex but warranted, given the variable acoustic detection histories evident for black sea bass of both known (i.e., positive and negative controls) and unknown fate. In previous studies, animal fate has been successfully reconciled by using solely the depth-variance test (e.g., for Atlantic cod; Capizzano et al., 2016) we employed in our study. However, when applied to our detection data, neither of these quantitative techniques was able to consistently predict the fate of all black sea bass (i.e., analyses with these techniques predicted different fates for nearly half of the detected fish), an outcome that was similar to that of previous work with haddock (*Melanogrammus aeglefinus*) in the Gulf of Maine (Capizzano et al., 2019). Because of this discrepancy, it was necessary to take a semiquantitative approach that both visually compared fish horizontal and vertical movements to those of positive and negative controls and predicted bottom currents in the study area to satisfactorily determine the fate of a large number of individuals. Although this approach lacked the full quantitative rigor of the depth-variance test, it was particularly effective at identifying predation events and at predicting the fate of fish with very short (i.e., hours) detection histories. Our methods can serve as a useful model for future studies, given that the analytical approaches for determining the fate of animals tagged with acoustic transmitters, as a part of discard mortality studies, frequently need to be developed specifically for a study and its unique factors, such as array design and animal behavior.

more than double the estimate (19%) of Rudershausen et al. (2014) for black sea bass captured at depths of 20–35 m, over 10 times greater than an estimate (4.7%) for black sea bass captured at depths of 6–12 m (Bugley and Shepherd, 1991), and comparable to estimates of immediate mortality (66%) following capture at depths >40 m (Stephen and Harris, 2010). On the basis of results of previous studies, it has been speculated that increased mortality at greater depths is attributable to barotrauma; however, results of our survival analysis on unvented fish captured at a depth of 45 m indicate that longer fight times also increase discard mortality. Therefore, it is likely that both vented and unvented black sea bass captured at depths greater than 45 m will experience higher discard mortality rates than reported herein because of both increased fight time and barotrauma. Additional research at depths greater than 45 m is needed to verify this assertion.

In contrast to previous studies, for example those by Rudershausen et al. (2014) on black sea bass and by Capizzano et al. (2016) on Atlantic cod (*Gadus morhua*), physical injury due to hook trauma or hook removal was

The successful identification of factors that influenced mortality, and therefore the discard mortality rate, of black sea bass in the winter offshore recreational fishery off New Jersey permitted formulation of recommendations for best practices in catch-and-release procedures aimed at reducing discard mortality. On the basis of the findings that swim bladder venting (when done correctly) was the most influential factor affecting discard mortality and that it increased submergence success over all depths (i.e., reduced the incidence of floating), we recommend that anglers vent all black sea bass before releasing them during the winter offshore fishery season. Given the finding that longer fight times (>54 s) increased mortality in the subsample of fish tagged with acoustic transmitters, another logical step is to explore methods to minimize the time black sea bass spend on the line while being reeled up to the surface.

Results of analysis with the generalized additive mixed-effect model indicate that capture depth had the largest influence on fight time; therefore, we recommend that anglers target black sea bass in water that is as shallow as possible. Although lower speed reels yielded longer fight times on average, the effect of individual angler had a seemingly large effect on the apparent relationship. In other words, angler behavior seemed to influence the effect that reel gear had on fight time more than the reel gear ratio itself. Given this finding, it is more logical (and practical) to recommend that anglers reel their catch to the surface at a moderate to fast pace, rather than to implement restrictions on reel gear. Capture as a part of a double header also resulted in increased fight time. Therefore, discard mortality may be reduced if anglers limit the number of hooks on their rigs. Also, we recommend that anglers use fishing gear (i.e., rod and reel or line) of appropriate strength for the area in which they fish to avoid unnecessary increases in fight time and discard mortality.

Acknowledgments

Literature cited

Allen, S. E., M. S. Dinniman, J. M. Klinck, D. D. Gorby, A. J. Hewett, and B. M. Hickey.
  2003. On vertical advection truncation errors in terrain-following numerical models: comparison to a laboratory model for upwelling over submarine canyons. J. Geophys. Res. 108:3-1–3-36. Crossref

Benoît, H. P., T. Hurlbut, and J. Chassé.
  2010. Assessing the factors influencing discard mortality of demersal fishes using a semi-quantitative indicator of survival potential. Fish. Res. 106:436–447. Crossref

Benoît, H. P., T. Hurlbut, J. Chassé, and I. D. Jonsen.
  2012. Estimating fishery-scale rates of discard mortality using conditional reasoning. Fish. Res. 125–126:318–330. Crossref

Benoît, H. P., C. W. Capizzano, R. J. Knotek, D. B. Rudders, J. A. Sulikowski, M. J. Dean, W. Hoffman, D. R. Zemeckis, and J. W. Mandelman.
  2015. A generalized model for longitudinal short- and long-term mortality data for commercial fishery discards and recreational fishery catch-and-releases. ICES J. Mar. Sci. 72:1834–1847. Crossref

Brownscombe, J. W., A. J. Danylchuk, J. M. Chapman, L. F. G. Gutowsky, and S. J. Cooke.
  2017. Best practices for catch-and-release recreational fisheries—angling tools and tactics. Fish. Res. 186:693–705. Crossref

Bugley, K., and G. Shepherd.
  1991. Management briefs: effects of catch-and-release angling on the survival of black sea bass. North Am. J. Fish. Manage. 11:468–471. Crossref

Burnham, K. P., and D. R. Anderson.
  2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd ed., 488 p. Springer-Verlag New York Inc., New York.

Capizzano, C. W., J. W. Mandelman, W. S. Hoffman, M. J. Dean, D. R. Zemeckis, H. P. Benoît, J. Kneebone, E. Jones, M. J. Stettner, N. J. Buchan, et al.
  2016. Estimating and mitigating the discard mortality of Atlantic cod (*Gadus morhua*) in the Gulf of Maine recreational rod-and-reel fishery. ICES J. Mar. Sci. 73:2342–2355. Crossref

Capizzano, C. W., D. R. Zemeckis, W. S. Hoffman, H. P. Benoît, E. Jones, M. J. Dean, N. Ribblett, J. A. Sulikowski, and J. W. Mandelman.
  2019. Fishery-scale discard mortality rate estimate for haddock in the Gulf of Maine recreational fishery. North Am. J. Fish. Manage. 39:964–979. Crossref

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 Am. J. Fish. Manage. 19:828–832. Crossref

Cooke, S. J., and C. D. Suski.
  2004. Are circle hooks an effective tool for conserving marine and freshwater recreational catch-and-release fisheries? Aquat. Conserv. 14:299–326. Crossref

Cox, D. R.
  1972. Regression models and life-tables. J. R. Stat. Soc., B 34:187–220.

Cox, D. R., and D. Oakes.
  1984. Analysis of survival data, 212 p. Chapman and Hall Ltd., London.

Crandall, C. A., T. M. Garlock, and K. Lorenzen.
  2018. Understanding resource-conserving behaviors among fishers: barotrauma mitigation and the power of subjective norms in Florida's reef fisheries. North Am. J. Fish. Manage. 38:271–280. Crossref

Curtis, J. M., M. W. Johnson, S. L. Diamond, and G. W. Stunz.
  2015. Quantifying delayed mortality from barotrauma impairment in discarded red snapper using acoustic telemetry. Mar. Coast. Fish. 7:434–449. Crossref

Davis, M. W.
    2002. Key principles for understanding fish bycatch discard mortality. Can. J. Fish. Aquat. Sci. 59:1834–1843. Crossref
Drumhiller, K. L., M. W. Johnson, S. L. Diamond, M. M. R. Robillard, and G. W. Stunz.
    2014. Venting or rapid recompression increase survival and improve recovery of red snapper with barotrauma. Mar. Coast. Fish. 6:190–199. Crossref
Eberts, R. L., and C. M. Somers.
    2017. Venting and descending devices provide equivocal benefits for catch-and-release survival: study design influences the effectiveness more than barotrauma relief method. North Am. J. Fish. Manage. 37:612–623. Crossref
Eberts, R. L., M. A. Zak, R. G. Manzon, and C. M. Somers.
    2018. Walleye responses to barotrauma relief treatments for catch-and-release angling: short-term changes to condition and behavior. J. Fish. Wildl. Manage. 9:415–430. Crossref
Hannah, R. W., P. S. Rankin, and M. T. O. Blume.
    2014. The divergent effect of capture depth and associated post-recompression survival of canary (*Sebsates pinniger*) and yelloweye rockfish (*S. ruberrimus*). Fish. Res. 157:106–112. Crossref
Harrington, D. P., and T. R. Fleming.
    1982. A class of rank test procedures for censored survival data. Biometrika 69:553–566. Crossref
Jarvis, E. T., and C. G. Lowe.
    2008. The effects of barotrauma on the catch-and-release survival of southern California nearshore and shelf rockfish (Scorpaenidae, *Sebastes* spp.). Can. J. Fish. Aquat. Sci. 65:1286–1296. Crossref
Kelley, D., and C. Richards.
    2017. oce: analysis of oceanographic data. R package, vers. 0.9-21. [Available from website, accessed February 2018.]
Knotek, R. J., D. B. Rudders, J. W. Mandelman, H. P. Benoît, and J. A. Sulikowski.
    2018. The survival of rajids discarded in the New England scallop dredge fisheries. Fish. Res. 198:50–62. Crossref
Lee, M.-Y., S. Steinback, and K. Wallmo.
    2017. Applying a bioeconomic model to recreational fisheries management: groundfish in the northeast United States. Mar. Resour. Econ. 32:191–216. Crossref
Moser, J., and G. R. Shepherd.
    2009. Seasonal distribution and movement of black sea bass (*Centropristis striata*) in the northwest Atlantic as determined from a mark-recapture experiment. J. Northw. Atl. Fish. Sci. 40:17–28. Crossref
NMFS (National Marine Fisheries Service).
    2018. Fisheries economics of the United States, 2016. NOAA Tech. Memo. NMFS-F/SPO-187, 243 p.
Ott, R. L., and M. Longnecker.
    2010. An introduction to statistical methods and data analysis, 6th ed., 1273 p. Brooks/Cole, Cengage Learning, Belmont, CA.
Pulver, J. R.
    2017. Sink or swim? Factors affecting immediate discard mortality for the Gulf of Mexico commercial reef fish fishery. Fish. Res. 188:166–172. Crossref
NEFSC (Northeast Fisheries Science Center).
    2017. 62nd Northeast regional stock assessment workshop (62nd SAW) assessment report. Northeast Fish. Sci. Cent. Ref. Doc. 17-03, 822 p. [Available from website.]

R Core Team.
    2018. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. [Available from website, accessed February 2018.]
ROMS/TOMS Group.
    2013. ROMS: Regional Ocean Modeling System. The ROMS/TOMS Group. [Available from website.]
Rudershausen, P. J., J. A. Buckel, and J. E. Hightower.
    2014. Estimating reef fish discard mortality using surface and bottom tagging: effects of hook injury and barotrauma. Can. J. Fish. Aquat. Sci. 71:514–520. Crossref
Runde, B. J., and J. A. Buckel.
    2018. Descender devices are promising tools for increasing survival in deepwater groupers. Mar. Coast. Fish. 10:100–117. Crossref
Sauls, B.
    2014. Relative survival of gags *Mycteroperca microlepis* released within a recreational hook-and-line fishery: application of the Cox regression model to control for heterogeneity in a large-scale mark-recapture study. Fish. Res. 150:18–27. Crossref
Scyphers, S. B., F. J. Fodrie, F. J. Hernandez Jr., S. P. Powers, and R. L. Shipp.
    2013. Venting and reef fish survival: perceptions and participation rates among recreational anglers in the northern Gulf of Mexico. North Am. J. Fish. Manage. 33:1071–1078. Crossref
Stephen, J. A., and P. J. Harris.
    2010. Commercial catch composition wit discard and immediate release mortality proportions off the southeastern coast of the United States. Fish. Res. 103:18–24. Crossref
Therneau, T. M., and P. M. Grambsch.
    2000. Modeling survival data: extending the Cox model, 350 p. Springer-Verlag New York Inc., New York.
Venables, W. N., and B. D. Ripley.
    2002. MASS: modern applied statistics with S, 4th ed., 495 p. Springer, New York.
Weltersbach, M. S., W.-C. Lewin, J. P. Gröger, and H. V. Strehlow.
    2019. Effect of lure and bait type on catch, size, hooking location, injury and bycatch in the western Baltic Sea recreational cod fishery. Fish. Res. 210:121–130. Crossref
White, J. W., and B. I. Ruttenberg.
    2007. Discriminant function analysis in marine ecology: some oversights and their solutions. Mar. Ecol. Prog. Ser. 329:301–305. Crossref
Wilde, G. R.
    2009. Does venting promote survival of released fish? Fisheries 34:20–28. Crossref
Winton, M. V., J. Kneebone, D. R. Zemeckis, and G. Fay.
    2018. A spatial point process model to estimate individual centers of activity from passive acoustic telemetry data. Methods Ecol. Evol. 9:2262–2272. Crossref
Wood, S. N.
    2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. J. R. Stat. Soc., B 73:3–36. Crossref
Yergey, M. E., T. M. Grothues, K. W. Able, C. Crawford, and K. DeCristofer.
    2012. Evaluating discard mortality of summer flounder (*Paralichthys dentatus*) in the commercial trawl fishery: developing acoustic telemetry techniques. Fish. Res. 115–116:72–81. Crossref