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Evaluation of factors contributing to postrelease mortality of greater amberjack (*Seriola dumerili*) in the northern Gulf of Mexico with depth and acceleration data from acoustic tags

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Abstract—Management of recreational fishing for greater amberjack (*Seriola dumerili*) in the Gulf of Mexico involves size regulations and closed seasons. Water temperature, salinity, fight and handling times, and barotrauma can influence survival of released fish. We examined postrelease mortality and behavior by using acoustic telemetry of the movements of 78 fish, monitored for up to 58 d across 3 sampling efforts in 2018, 2019, and 2020 over a depth gradient of 29–64 m. To assess descender devices as a mitigation tool, we assigned fish to 2 treatments: surface release without swim bladder venting and release with a descender device. Cox proportional hazards models were used to assess the effects of site depth, release treatment, bait type (jigging or live bait), fishing injury, tagging injury, fight and handling times, surface and bottom temperatures, and fish length. We found neither a positive association between mortality risk and site depth, as might be expected from barotrauma, nor increased survivorship for fish released with a descender device. The best-supported model considered only fish length as a factor in postrelease mortality; legal-size fish (≥864 mm in fork length) had a mortality risk 20 times greater than that of smaller fish. Our results indicate that sublegal-size fish released because of size restrictions face much lower mortality risk than legal-size fish.

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The greater amberjack (*Seriola dumerili*) is a cosmopolitan tropical and temperate predatory fish taken in recreational and commercial fisheries (Smith-Vaniz, 2002). In the Gulf of Mexico, the greater amberjack is considered overfished and currently experiencing overfishing (SEDAR, 2020). Past amendments to the Gulf of Mexico Fishery Management Council fishery management plan included requirements for the use of non-stainless-steel circle hooks with natural baits, an increase in the recreational minimum size from 762 mm (30 in) to 864 mm (34 in) in fork length (FL), and seasonal closures during open recreational seasons for red snapper (*Lutjanus campechanus*) and other reef fish species (SEDAR, 2020). These factors make it likely that more greater amberjack will be caught at sublegal sizes (<864 mm FL at the time of the study) and out of season and then released. Therefore, there is a need to gain a better understanding of factors that contribute to discard mortality.

Greater amberjack discarded in recreational fisheries face several potential sources of mortality. These sources include the following: 1) at-vessel mortality (AVM), meaning a death after a fish is hooked but before landing; 2) capture and handling mortality (CHM), meaning a lethal event during capture and handling after landing that prevents successful release; and 3) postrelease mortality (PRM).

Several factors have been predicted to affect discard mortality associated with recreational fishing for greater amberjack. Swim bladder barotrauma is associated with increased PRM risk for some reef fishes (Curtis et al., 2015; Runde and Buckel, 2018). Swim bladders in acanthomorph fishes, like the greater amberjack, lack a pneumatic connection to the gut and are termed physoclistous (Lagler et al., 1962). Physoclistous fishes cannot expel gas from the swim bladder lumen through the pharynx and as a result must resorb gas into the blood stream through the oval (Woodland, 1913). Therefore, depth-related pressure changes from rapid fishing ascents may cause injury to swim bladder tissues, increase stress, and make descent to deeper habitats difficult for fish after release. Results from a previous study of red snapper indicate that barotrauma is associated with both immediate discard mortality (AVM in our study) and delayed mortality (PRM in our study) (up to 72 h postrelease) and that barotrauma can be mitigated by venting the swim bladder or using a descender device to recompress the swim bladder and then releasing the fish at depth (Curtis et al., 2015).

Other factors may contribute to AVM and PRM in reef fishes like the greater amberjack. Fight time during fishing may raise risk of AVM and PRM by increasing stress (Mohan et al., 2020), depleting energy, and elevating predation risk. In addition, fight time may increase with fish size and fishing depth, and the combined factors may contribute to mortality. Water temperature, salinity, and dissolved oxygen may also be additional sources of physiological stress.

Biotelemetry was used to assess PRM in greater amberjack at artificial reefs off the coast of Alabama (Jackson et al., 2018). Using depth-logging acoustic tags to study fish that were vented and released, Jackson et al. (2018) found a PRM estimate (18.8%) similar to the estimate for 1 of 3 modeled PRM scenarios in a stock assessment from the same time (SEDAR, 2014). In our study, we caught greater amberjack in the northern Gulf of Mexico using common recreational angling techniques in 2018, 2019, and 2020. We used direct observation to calculate AVM and CHM and used data from acceleration- and depth-logging acoustic tags to estimate PRM of fish released at the surface or with a descender device. The main study objectives were 1) to estimate survivorship and associated PRM of discarded greater amberjack and 2) to evaluate the following factors as potential predictors of PRM risk: fish size, fight and handling times, use of a descender device, site depth, capture method (live bait or jigging), observed fishing and tagging injuries, and water temperature at the surface and on the bottom.

Materials and methods

Receiver deployment

Vemco VR2AR[1] acoustic receivers (Innovasea Systems Inc., Boston, MA) were deployed at 16 sites on artificial reefs before each study period in 2018, 2019, and 2020. Artificial reefs were steel and concrete pyramids, sunken boats, a barge, an oil rig jacket, a fuel tank, a grain hopper, and a submarine (Suppl. Table 1). One or 2 receivers were placed near each site (Suppl. Table 1). For deployment, VR2AR receivers were attached to cement moorings with approximately 2 m of polypropylene line attached to the detachable lug, and a midline swivel was present between the mooring and lug to prevent twisting. Two noncompressible 20-cm (8-in) trawl floats were attached to the receiver collar with 3.5-m of polypropylene line with a midline swivel to provide buoyancy. Each assembled receiver, along with its moorings and floats, was deployed at the sea surface and released with the manufacturer's acoustic release function with a Vemco VHTx-69k transponding hydrophone (Innovasea Systems Inc.) and VR100 receiver (Innovasea Systems Inc.) at the end of each study period.

[1] Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

Fish collection and tagging

Tagging took place on 16–17 and 23–24 August 2018, on 30 April and 13–14 May 2019, and on 17–18 and 21–22 August 2020. These dates were chosen on the basis of the availability of personnel and vessels and the aim to provide an opportunity to examine mortality under different water temperatures and at different fish sizes, which varied among the 3 study periods.

Greater amberjack were caught and tagged by following common recreational fishing methods on chartered boats (FV *Lady Ann* and FV *Escape*). Fish were caught by using 2 methods opportunistically, either with live bait (11/0 or 12/0 circle hooks, 340–450-g weights, and a 36.3–45.4-kg test monofilament leader with a swivel tied to the mainline) or with artificial lures (140–170-g jig heads with soft plastic lures). A data recorder on board, using a stopwatch, noted the time from when an angler first had a fish on the line to when the fish was landed (fight time, in seconds) and the time from the landing to the release of a fish (handling time, in seconds). Upon their landings, fish were immediately measured and ventilated with a saltwater hose. Standard, fork, natural total, and stretch total lengths were recorded to the nearest millimeter. Injuries to fish were noted prior to release, and all dead fish prior to landing (AVM events) were recorded.

Fishing release treatment (surface or descender device) was alternated in the order that fish were landed. Before fishing began each day, we randomly chose the starting release treatment. For the release treatment in which a descender device was used, a SeaQualizer Descending Device (standard model, SeaQualizer, Davie, FL) was attached to the fish's lower jaw and set to the deepest possible release depth (increments of 15.2 m, 30.5 m, and 45.7 m) at each site, requiring a release depth less than the site depth. The fish and descender device were lowered with approximately 2.3 kg of weight attached to a fishing rod along with a digital video camera (Hero5 Black Edition, GoPro Inc., San Mateo, CA) for observing potential predation.

Results from a previous study (Jackson et al., 2018) indicate that the observed "release condition" of a fish was indicative of PRM risk. We assigned a number for the release condition (Patterson et al., 2001; Jackson et al., 2018) of fish released at the surface as follows: 1, fish immediately oriented and swam downward rapidly; 2, fish appeared disorientated and swam down slowly; 3, fish appeared disoriented and remained at the surface for several minutes; and 4, fish was dead and unresponsive at the surface. It was not possible to assess release condition for fish released with a descender device because fish drifted out of the view of the camera in most cases.

Fish were tagged with Vemco V9AP depth and accelerometry acoustic transmitters (Innovasea Systems Inc.) coded with the following parameters: activity algorithm, triaxial root mean square of acceleration, 5 samples/s, 20–40-s delay, accelerometer range of ±4.9 m/s, high power setting, a slope (resolution) of 0.3 m for depth, depth range of 68 m, and acceleration-to-depth transmission ratio of 1:1. We initially attached transmitters externally on fish rather than intraperitoneally to avoid inadvertent swim bladder venting that could result from surgical implantation and that might interfere with testing of barotrauma effects. In 2018, acoustic transmitters were attached externally on a second external dart tag (Floy FH-69 stainless-steel dart tag, Floy Tag Inc., Seattle, WA), with the tag attached to the dart with a 68-kg monofilament line. Dart tags were inserted and locked to interneurals (pterygiophores) below the spiny dorsal fin on the left side. Prior to tagging, acoustic transmitters were attached to tags with marine epoxy and 2 zip ties, with the transmitter's longitudinal axis parallel to the external tag. A second dart tag (FIM-96 nylon dart tag, Floy Tag Inc.), with a unique tag ID, phone number, and website URL on it, was placed caudally to the stainless-steel dart tag on the fish's left side.

Because of acoustic transmitter shedding (see the "Results" section) in 2018, we modified the tagging procedure for 2019 and 2020. Vemco V9AP accelerometer transmitters were placed intraperitoneally through a small incision, just wide enough to pass the transmitter. The incision was made in the left abdomen, just dorsal (1–2 cm) and anterior (1–2 cm) to the cloaca. The swim bladder was not visible in any tagging surgeries, and no evidence of venting was observed. After tag implantation, incisions were closed with 2 interrupted sutures by using monofilament suture thread. In addition to acoustic transmitters, fish received a dart tag with ID and contact information as described above: FIM-96 tags were used in 2019, and FH-69 tags were used in 2020.

Postrelease fate inferred from acoustic telemetry

We used depth and acceleration data from tagging of fish to infer their fate (Whitney et al., 2016). We tabulated raw depth and acceleration data from receivers by time and examined graphs of all raw data. We plotted raw data over an approximately 5-d period (if available) at the end of the detection period for each fish or, in the cases of suspected mortality or tags that had been shed (see the "Postrelease fate based on acoustic telemetry" subsection in the "Results" section), over the time period of suspected death or tag shedding. Fish were determined to be dead when transmissions indicated that the tag was on the bottom and acceleration had ceased. Rapid onset of high acceleration values were predicted to indicate possible predation or carcass scavenging.

Survivorship

We estimated overall survivorship, accounting for all sources of discard mortality (AVM, CHM, and PRM); at-vessel survivorship, accounting for AVM and CHM; and postrelease survivorship, accounting for PRM. Survivorship ($\hat{S}$) and its standard error (SE) were estimated from acoustic telemetry (see the "Results" section) and data on recapture of fish by using equations 17 and 18 of Pollock and Pine (2007):

$$\hat{S} = \frac{x}{n}, \tag{1}$$

$$SE(\hat{S}) = \sqrt{\frac{\hat{S}(1-\hat{S})}{n}}, \tag{2}$$

where x = the number of surviving fish; and
n = the number of fish: in the context of this equation, total number of fish caught or dead prior to landing for estimates of overall survivorship, number of fish landed for at-vessel survivorship, or number of fish released for postrelease survivorship.

We produced Cox proportional hazards models (Cox, 1972) to test for the contribution of factors (i.e., fishing related variables, abiotic conditions, release treatment, and fish size) to postrelease mortality. Cox models were produced by using the survival package (vers. 3.2-13; Thernau, 2021) in R (vers. 4.1.1; R Core Team, 2021). For all models, we report the statistic from the likelihood ratio test in which models were compared to a null model and the P-values for each test and their associated model predictors. Separate models were run for externally tagged fish and internally tagged fish because many fish in the former group shed their transmitters. Only some fish were recaptured, and because it is not possible to determine death events after acoustic tags ceased to transmit data for fish that were not recaptured, we restricted the observation period of our Cox models and survivorship curves to the period when acoustic tags were transmitting and receivers were deployed. This restricted observation period did not change model outcomes but limited the duration of survivorship curves to <60 d. All 9 recaptured fish had transmitters that were detected until the end of predicted transmitter battery life or receiver retrieval, but 4 of these fish were externally tagged fish that shed their acoustic tags. Acceleration and depth data from the tags attached to these 4 fish indicate that tags were shed within range of receivers while they were still transmitting (see the "Results" section).

We initially considered the following potential predictors: FL (in millimeters); fight and handling times; release treatment (categorical, fish released at surface or with descender device); site depth; bait type (categorical, live bait or jigging); fishing injury (categorical, no injury versus visible injury from fishing gear before handling and tagging); tagging injury (categorical, no injury versus visible bleeding from site of external tagging); surface, mid-depth, and bottom water temperatures; surface, mid-depth, and bottom salinities; and surface, mid-depth, and bottom dissolved oxygen. Barotrauma injuries (e.g., expanded swim bladders and bulging eyes) were not included in models because they were never observed, although internal tissue damage may have been present. Release condition was not tested because that information was not available for fish released with a descender device. Before including predictors in Cox models, we tested for correlation among predictors with Spearman rank correlation tests (Kneebone et al., 2021) (Suppl. Table 2). Many abiotic variables (e.g., temperature, salinity, and dissolved oxygen) were highly correlated (Suppl. Table 2); therefore, we reduced the analysis to include bottom and surface temperature as the only abiotic variables. Several additional correlations were observed among other predictors included in initial Cox models (e.g., fight time and fish length; Suppl. Table 2), and these correlations are considered in our interpretation of results.

The internal placement of tags in fish in 2019 and 2020 may have caused additional handling stress, and although attempts were made to not vent the swim bladder, we inadvertently may have partially vented it. Therefore, we used separate Cox models to analyze fish with transmitters placed externally (in 2018) and those with transmitters placed intraperitoneally (in 2019 and 2020). Stepwise model selection was conducted with the stepAIC function from the package MASS (vers. 7.3-54; Venables and Ripley, 2002) in R, and both forward and backward selections were attempted to select the model with the lowest Akaike information criterion (AIC). We used the AIC with correction for small sample sizes (AICc) (Burnham and Anderson, 2002) and considered models with a difference in AICc from that of the best model (ΔAICc) of 2 units or less to have comparable support, unless the model with more variables differed by addition of a single parameter, indicating a potentially spurious variable (Burnham and Anderson, 2002).

Predictor data were missing for several fish: fight time (1 fish from 2018), handling time (1 fish from 2018), bottom temperature (14 fish from 2019 and 2020), and fight and handling times (6 fish from 2019 and 2020). Therefore, to explore all factors, we began with full models for the subset of fish with available predictor data and completed stepwise AICc model selection. In one instance, for internally tagged fish with bottom temperature data available, the full model was overparameterized and did not converge. We ran exploratory models with single predictors and removed predictors with the highest AICc before running the stepwise procedure on the fullest model that would converge. We then ran separate procedures for stepwise AICc model selection on the complete data sets (externally tagged fish from 2018 [number of fish (n)=23] and internally tagged fish from 2019 and 2020 [n=55]) that did not include the predictors that were missing for some fish.

Kaplan–Meier survival function curves were generated for variables informed by Cox models by using the survfit function in the survival package in R and were plotted with the survminer package (vers. 0.4.9; Kassambra et al., 2021) in R.

Results

We tagged 78 greater amberjack at 15 artificial reef sites that ranged in depth from 29 to 64 m during separate efforts in 2018, 2019, and 2020 (Table 1). Three fish died before successful release (Table 1). Fish D1 died on the boat and was bleeding severely from the hook site (classified as a CHM). Fish D2 died from a propeller injury, and fish D3 died from predation by a shark before landing (both considered an AVM). All other fish released at the surface had a release condition of 1. In underwater video from the descender rig, fish were usually out of view because of a long leader between the camera and fish. Therefore, fish released with a descender device near the bottom were rarely observed, and it was not possible to determine their release condition. Further, no predation or potential predators (e.g., carcharhinid sharks) were observed on video.

Fourteen acoustically tagged fish were detected on receivers at reefs where they were not originally tagged (Table 1). Three of these 14 fish, fish 118, 120, and 121, were detected on 2 reefs at close proximity (0.5 km apart) throughout the study. Six fish tagged in 2020 (fish 53, 58, 104, 105, 107, 115) were not detected on the first day after being tagged and released (Table 1).

Postrelease fate based on acoustic telemetry

Patterns of acceleration and depth over time were distinct among fish determined to have died versus lived. Seven fish acoustically tagged during 2018–2020 were inferred to have died (Fig. 1, Table 2). Profiles from tags of dead fish indicate only brief depth changes and acceleration oscillations greater than 2 m/s^2 (Fig. 1, Table 2). Fish 22, 31, 51, 117, and 119 were dead very soon after release (≤2 h), and fish 23 and 47 remained alive longer (Fig. 1, Table 2). In contrast, fish inferred to have lived had strong and consistent depth and acceleration oscillations until the end of predicted transmitter battery life or deployments of acoustic receiver arrays, until they emigrated from receiver arrays, or in the case of some fish with externally placed transmitters (as was done in 2018), until their tag was shed (Fig. 2, Table 2, Suppl. Figs. 1 and 2, Suppl. Table 2).

Acceleration and depth profiles indicate that 13 of 23 fish tagged in 2018 shed their tags, and information on the recapture of fish by anglers confirms this outcome in 4 instances (Table 1); secondary external tags were not shed. Results of analysis of the carcass of a recaptured fish indicate that the stainless-steel dart remained in place but that the monofilament line attachment point broke on the dart, perhaps as a result of drag on the tag or the fish actively scraping the tag off. No tags that were intraperitoneally placed in 2019 or 2020 were shed. Telemetry profiles for fish inferred to have shed tags indicate relatively consistent depth and acceleration oscillations that abruptly ended at the time of the presumed tag shedding (Fig. 2, Table 2, Suppl. Figs. 1 and 2, Suppl. Table 3). The tag records for fish inferred to have shed tags differed from the tag records of fish presumed to have died; for fish that died, acceleration and depth variation was evident but less consistent during the brief period before their apparent death (Fig. 1). Ten fish were detected briefly (<4 h)

Table 1

Summary of tagging effort and the fork lengths (FLs) and fates for greater amberjack (*Seriola dumerili*) caught on charter boats in the northern Gulf of Mexico during 2018–2020. Tagged fish were released either at the surface (S) or with a descender device (DC). In 2018, fish had an acoustic tag attached to a primary external tag (Ex.), and in 2019 and 2020, fish had an acoustic transmitter placed intraperitoneally (In.), in addition to a secondary external tag. Symbols after the last detection date indicate if the tag was shed (st) or if the fish was recaptured (†). Fish <864 mm FL were of sublegal size. Either jigging (J) or live bait (L) was used to catch fish. Fates of fish include alive (A), dead (D), lived until recaptured (R), emigrated outside of detection range during the life of the transmitter battery and before receivers were retrieved (E), moved between sites with receivers (M), and unknown because the fish spent <68 h in the receiver array (U). Symbols in the "Fate" column indicate that the external tag was shed, either determined from acceleration and depth data (*) or confirmed from angler recapture (**). Fish D1 was dead before release, fish D2 died from a propeller injury before landing, and fish D3 died of predation before landing. UK=unknown because no data were taken.

Fish ID	Release type	Tag type	Site depth (m)	Tagging date	Detection date		FL (mm)	Bait type	FT (s)	HT (s)	Fate
					First	Last					
01	S	Ex.	30.5	16-Aug-2018	16-Aug-2018	23-Aug-2018[st]	950	L	99	146	A[*]
02	DC	Ex.	33.2	16-Aug-2018	16-Aug-2018	16-Aug-2018	1006	L	172	126	U
03	S	Ex.	33.2	16-Aug-2018	16-Aug-2018	1-Aug-2019[†]	750	L	73	137	R[**]
04	DC	Ex.	37.0	16-Aug-2018	16-Aug-2018	5-Jun-2019[†]	995	L	250	155	R[**]
05	S	Ex.	37.0	16-Aug-2018	16-Aug-2018	17-Sep-2018[st]	630	J	145	135	A[*]
06	DC	Ex.	37.0	16-Aug-2018	16-Aug-2018	12-Sep-2018[st]	527	J	54	UK	A[*]
07	S	Ex.	37.0	16-Aug-2018	16-Aug-2018	23-Aug-2018[st]	1100	L	UK	22	A[*]
08	DC	Ex.	45.0	16-Aug-2018	16-Aug-2018	21-Aug-2018[st]	895	L	141	159	A[*]
09	S	Ex.	45.0	16-Aug-2018	16-Aug-2018	16-Aug-2018	930	L	108	72	U
10	DC	Ex.	45.0	16-Aug-2018	16-Aug-2018	19-Sep-2018[†]	940	L	173	107	R[**]
11	S	Ex.	45.0	16-Aug-2018	16-Aug-2018	16-Aug-2018[st]	900	L	171	58	A[*]
12	DC	Ex.	49.0	16-Aug-2018	16-Aug-2018	8-Oct-2018	855	L	117	151	A
13	S	Ex.	52.4	17-Aug-2018	17-Aug-2018	17-Aug-2018	984	L	134	98	AE
14	DC	Ex.	52.4	17-Aug-2018	17-Aug-2018	17-Aug-2018	1029	L	185	75	U
15	S	Ex.	52.4	17-Aug-2018	17-Aug-2018	17-Aug-2018	986	L	167	93	U
16	DC	Ex.	38.0	17-Aug-2018	17-Aug-2018	17-Aug-2018	896	L	170	117	AE
17	S	Ex.	38.0	17-Aug-2018	17-Aug-2018	17-Aug-2018[st]	917	J	269	62	U[*]
18	DC	Ex.	38.0	17-Aug-2018	17-Aug-2018	17-Aug-2018	905	L	99	210	U
19	S	Ex.	38.0	17-Aug-2018	17-Aug-2018	17-Aug-2018[st]	966	J	260	58	AE[*]
20	DC	Ex.	38.0	17-Aug-2018	17-Aug-2018	17-Aug-2018[st]	919	L	154	93	A[*]
21	S	Ex.	33.2	23-Aug-2018	23-Aug-2018	5-Jun-2019[†]	836	L	98	129	R[**]
22	DC	Ex.	33.2	23-Aug-2018	23-Aug-2018	23-Aug-2018	779	L	100	157	D
23	S	Ex.	37.0	23-Aug-2018	23-Aug-2018	26-Aug-2018	540	J	55	70	D
24	DC	In.	29.1	30-Apr-2019	30-Apr-2019	25-Jun-2019	835	J	UK	UK	A
25	S	In.	29.1	30-Apr-2019	30-Apr-2019	23-May-2019	736	L	UK	UK	AE
26	DC	In.	29.1	30-Apr-2019	30-Apr-2019	6-Jan-2020[†]	730	L		UK	R
27	S	In.	29.1	30-Apr-2019	30-Apr-2019	15-Oct-2021[†]	730	L		UK	R
28	DC	In.	64.0	30-Apr-2019	30-Apr-2019	2-Aug-2019[†]	829	L		UK	R
29	S	In.	64.0	30-Apr-2019	30-Apr-2019	23-May-2019	825	L		UK	AE
30	DC	In.	64.0	30-Apr-2019			1030	L	156	318	U
31	S	In.	64.0	30-Apr-2019	30-Apr-2019	30-Apr-2019	983	L	374	278	D
32	DC	In.	32.3	13-May-2019	13-May-2019	25-Jun-2019	718	J	99	320	AM
33	S	In.	32.3	13-May-2019	13-May-2019	25-Jun-2019	735	L	10	219	A
34	DC	In.	32.3	13-May-2019	13-May-2019	31-May-2019	707	J	112	228	AE
35	S	In.	32.3	13-May-2019	13-May-2019	25-Jun-2019	720	L	90	136	AM
36	DC	In.	36.9	13-May-2019	13-May-2019	25-Jun-2019	634	J	90	285	A
37	S	In.	36.9	13-May-2019	13-May-2019	25-Jun-2019	703	L	60	189	A
38	DC	In.	64.0	14-May-2019	14-May-2019	22-Jun-2019	650	J	96	534	AE
39	S	In.	64.0	14-May-2019	14-May-2019	22-Jun-2019	809	L	115	355	AE
40	DC	In.	64.0	14-May-2019	14-May-2019	24-May-2020[†]	705	L	120	430	R
41	S	In.	64.0	14-May-2019	14-May-2019	25-Jun-2019	800	J	165	394	A
42	DC	In.	64.0	14-May-2019	14-May-2019	22-Jun-2019	734	L	108	538	AE
43	S	In.	29.1	14-May-2019	14-May-2019	25-Jun-2019	656	L	47	248	A
44	DC	In.	29.1	14-May-2019	14-May-2019	27-May-2019	716	J	100	445	AE
45	S	In.	29.1	14-May-2019	14-May-2019	27-May-2019	705	J	130	548	A
47	DC	In.	37.0	17-Aug-2020	17-Aug-2020	27-Aug-2020	961	L	177	324	D

(*Continued on next page*)

Table 1 (*continued*)

Fish ID	Release type	Tag type	Site depth (m)	Tagging date	Detection date First	Detection date Last	FL (mm)	Bait type	FT (s)	HT (s)	Fate
48	S	In.	37.0	17-Aug-2020	17-Aug-2020	18-Aug-2020	601	L	73	243	UME
49	DC	In.	37.0	17-Aug-2020	17-Aug-2020	14-Sep-2020	1050	L	170	286	AME
50	S	In.	36.1	17-Aug-2020	17-Aug-2020	21-Aug-2020	920	L	117	223	AME
51	DC	In.	36.1	17-Aug-2020	17-Aug-2020	17-Aug-2020	1064	L	358	241	D
52	S	In.	34.8	18-Aug-2020	18-Aug-2020	1-Oct-2020	785	L	87	203	A
53	DC	In.	34.8	18-Aug-2020	25-Aug-2020	23-Sep-2020	804	L	285	175	AME
54	S	In.	34.8	18-Aug-2020			895	L	45	152	U
55	DC	In.	34.8	18-Aug-2020	18-Aug-2020	18-Aug-2020	800	L	367	165	U
56	S	In.	34.8	18-Aug-2020	30-Aug-2020	1-Oct-2020	780	L	386	234	A
57	DC	In.	34.8	18-Aug-2020	18-Aug-2020	1-Oct-2020	773	L	411	149	A
58	S	In.	34.8	18-Aug-2020	28-Aug-2020	1-Oct-2020	715	L	332	146	A
59	DC	In.	34.8	18-Aug-2020	18-Aug-2020	1-Oct-2020	810	L	295	281	A
101	S	In.	34.8	18-Aug-2020			980	L	341	155	U
103	DC	In.	34.8	18-Aug-2020			845	L	175	225	U
104	DC	In.	34.8	18-Aug-2020	28-Aug-2020	14-Sep-2020	845	L	115	225	AE
105	S	In.	34.8	18-Aug-2020	30-Aug-2020	1-Oct-2020	785	L	264	198	A
106	DC	In.	34.8	18-Aug-2020	18-Aug-2020	1-Oct-2020	787	L	424	196	A
107	S	In.	38.0	18-Aug-2020	29-Aug-2020	26-Sep-2020	800	L	113	207	AE
108	DC	In.	38.0	18-Aug-2020	18-Aug-2020	1-Oct-2020	515	L	28	172	AM
109	S	In.	38.0	18-Aug-2020	18-Aug-2020	1-Oct-2020	751	L	130	185	AM
110	DC	In.	38.0	18-Aug-2020	18-Aug-2020	18-Aug-2020	520	J	75	125	U
111	S	In.	38.0	18-Aug-2020	18-Aug-2020	15-Sep-2020	491	J	112	124	AME
112	DC	In.	38.0	18-Aug-2020			476	J	100	121	U
113	S	In.	38.0	18-Aug-2020	18-Aug-2020	26-Aug-2020	824	L	126	159	AE
114	DC	In.	38.0	18-Aug-2020	18-Aug-2020	1-Oct-2020	750	L	146	243	AM
115	S	In.	36.1	21-Aug-2020	22-Aug-2020	24-Aug-2020	959	L	202	188	UME
116	S	In.	36.1	21-Aug-2020	21-Aug-2020	14-Sep-2020	1004	L	331	151	AE
117	S	In.	36.1	21-Aug-2020	21-Aug-2020	21-Aug-2020	945	L	125	171	D
118	DC	In.	47.8	22-Aug-2020	22-Aug-2020	25-Sep-2020	774	L	116	157	AE
119	S	In.	47.8	22-Aug-2020	22-Aug-2020	22-Aug-2020	641	L	57	177	D
120	DC	In.	47.8	22-Aug-2020	22-Aug-2020	1-Oct-2020	865	L	147	105	R
121	DC	In.	47.8	22-Aug-2020	22-Aug-2020	22-Aug-2020	476	L	37	472	U
D1	–	–	37.0	16-Aug-2018	–	–	510	J	29	–	D
D2	–	–	37.0	23-Aug-2018	–	–	1023	L	243	–	D
D3	–	–	33.2	16-Aug-2018	–	–	UK	L	180	–	D

(Fig. 3). Few detections occurred for these fish, but the depth and acceleration values were similar to fish that lived (Fig. 3, Table 2). Five fish were never detected by any receivers (Table 1).

Among released fish that died, 4 greater amberjack (57%) were released at the surface and 3 fish (43%) were released with a descender device. For externally tagged fish for which PRM was not observed, the length of time during which their tags were detected in 2018 was variable (median: 7.8 d; 1st quartile: 2.8 d; 3rd quartile: 33.0 d) because some fish shed their transmitters and were not recaptured and some likely emigrated away from reefs with acoustic receivers. For internally tagged fish, the length of time during which their tags were detected in 2019 and 2020 were longer (median: 38.9 d; 1st quartile: 14.1 d; 3rd quartile: 43.8 d). Eight fish were captured 90 d or later (maximum: 899 d) after tagging.

Recapture rate and postrelease survivorship

The fish recapture rate from recreational and commercial angling (fishing mortality rate) was 11.5%. In 2018, acoustic tags were placed externally. Postrelease mortality was inferred from acceleration and depth data for 2 fish in 2018, 1 fish in 2019, and 4 fish in 2020, or 9% of fish tagged in all 3 years combined.

We estimated survivorship with data for all fish in the study except fish that either were never recaptured or were detected acoustically for less than 68 h, the latest observed PRM event (Fig. 1). Overall survivorship after accounting for all sources of discard mortality, AVM, CHM, and PRM (i.e., including the 3 fish that died before release), was moderate ($\hat{S}$=84.6% [SE 4.1]). At-vessel survivorship following AVM and CHM was 94.8% (SE 4.4), and postrelease survivorship was 88.7% (SE 4.2).

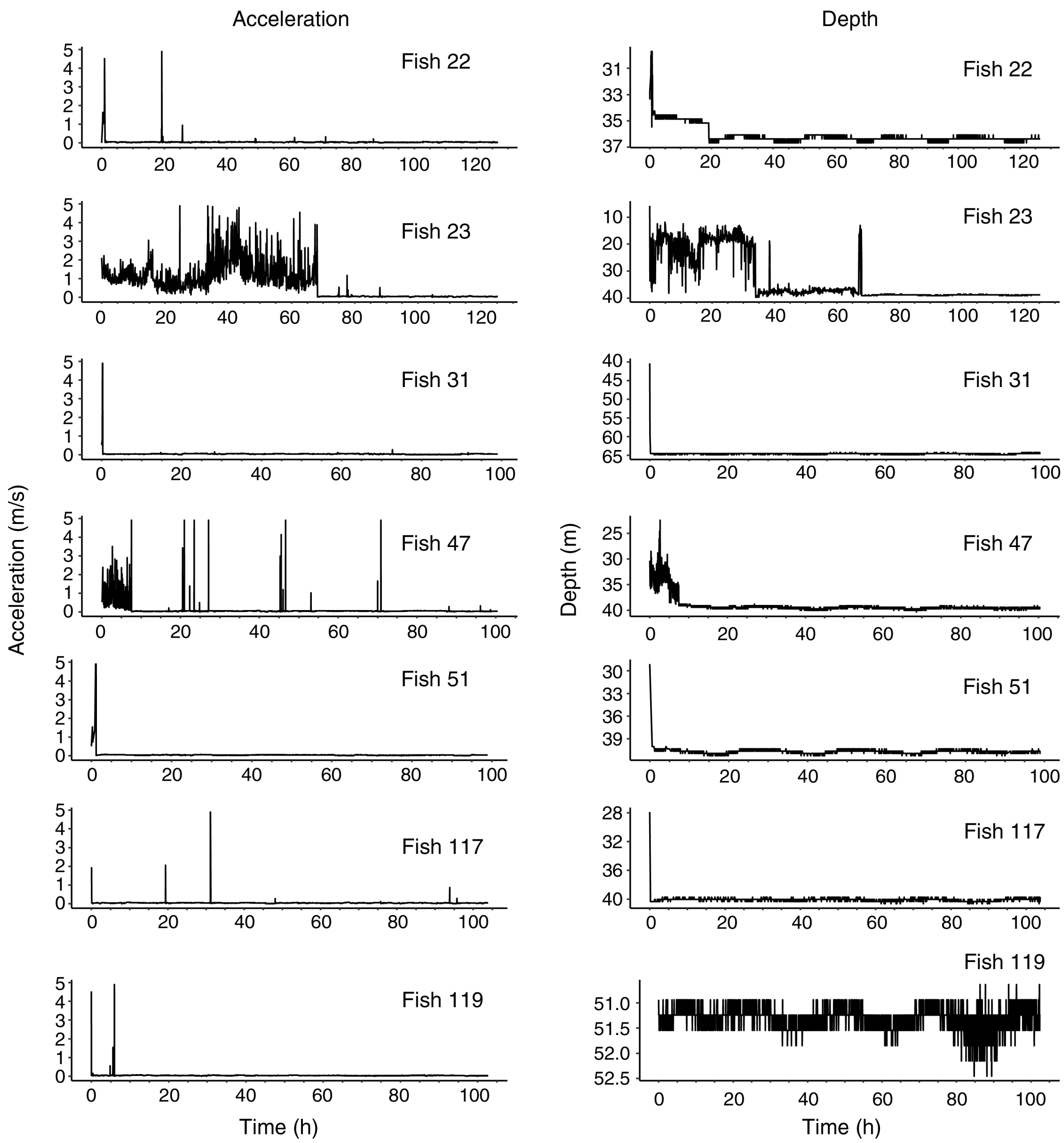

Figure 1

Acceleration and depth profiles from acoustic telemetry for tagged greater amberjack (*Seriola dumerili*) in the northern Gulf of Mexico inferred to have died after release. Table 2 provides the rationale for the fate and time of inferred death of each fish. Fish were caught and tagged on charter boats during 2018–2020.

Cox proportional hazards models: factors of postrelease mortality

The 2 best models used to examine PRM of fish tagged with external transmitters in 2018 received comparable support (ΔAICc: 0.86), and both included bait type and surface temperature as predictors (Table 3). In the second-best model, bait type and surface temperature were significant predictors (Table 3); however, the very small hazard ratios associated with these predictors indicate a tiny decrease in mortality associated with fish caught on a jig and an even smaller decrease in mortality with each 1°C increase in surface temperature. No predictors were significant in the best model, which also included fishing injury as a variable (Table 3). Effects of fight and handling times were tested by using a subset of data from 2018 for fish for which these values were available, and these factors were not significant predictors of mortality in any of the models used in this study (Suppl. Tables 4–6). The Kaplan–Meier survivorship curve for fish tagged externally in 2018 (Fig. 4) indicates that survival probability dropped to 94.7% 2 h postrelease and to 88.8% 68 h postrelease and then remained at that level throughout the rest of the period of acoustic monitoring.

Table 2

Fates of 25 greater amberjack (*Seriola dumerili*) tagged and released between 2018 and 2020 in the northern Gulf of Mexico, inferred with depth and acceleration data from acoustic tags. Fates include alive (A), alive and detected on 2 separate reef sites before emigrating away from the receiver array (AME), alive and emigrated (AE), alive and shed tag (AST), alive but detected for <68 h (U), alive and detected on 2 separate reef sites for 68 h (UM), and dead (D). Also noted for each fish are the figure (Fig.) showing acceleration and depth data that were recorded before and continued to be recorded until the last acoustic detection or fate assignment and either the time from release to fate assignment determined from acoustic telemetry data (alive, dead, or shed tag) or the date the fish was recaptured.

Fish ID	Fate	Rationale for fate assignment	Fig.	Time to fate (h) or recapture date
22	D	Brief acceleration activity and little depth variation indicates fish remained near bottom (at depth of ~36.5 m) and ventured up to a depth of only 30 m. Appears to have died within 2 h postrelease. Movement seen in slightly deeper water 20 h after first detection consistent with movement of carcass by scavengers or of tag by currents.	1	2.00
23	D	Appears near bottom from 34 to 67 h postrelease, but acceleration indicates fish still moving vigorously. Makes one last foray to shallow water (depths of 38.5–15.5 m) ~67 h postrelease (perhaps dragged by a predator and dropped). Tag remains on bottom after 68 h.	1	67.97
31	D	Brief, strong acceleration quickly ceases. Depth values drop quickly, indicating that fish is dead on the bottom.	1	0.28
47	D	Acceleration stops suddenly at time of death with additional brief peaks (~20, ~45, and ~70 h postrelease) not associated with depth changes but consistent with movement of carcass by scavengers or of tag by currents.	1	7.62
51	D	Acceleration stops suddenly, and fish is at the bottom (depth of ~39 m) within 1.20 h postrelease.	1	1.20
117	D	Detected on the bottom (depth of ~40 m), and acceleration stopped within 0.20 h postrelease. Additional, isolated accelerations at ~20, 30, and 94 h postrelease consistent with movement of carcass by scavengers or of tag by currents.	1	0.20
119	D	Appears dead within 1 min of release. Only one acceleration transmission indicative of fish movement and first depth detections occur on bottom at depth of ~51.5 m. Additional movement ~6 h postrelease is consistent with movement of carcass by scavengers or of tag by currents.	1	0.02
01	AST	Tag shed (inferred) 166 h postrelease. Consistent variation of acceleration and depth and an immediate cessation of movement when tag is on bottom, at a depth of ~33 m. Note similarity to depth and acceleration profiles of fish 03, 08, and 10 in Figure 2.	2	166.38
03	AST	Tag shed, confirmed from recapture by angler. Tag appears to have been shed 164 h postrelease. Note similarity to fates of fish 01, 08, and 10.	2	1-Aug-2019
08	AST	Tag shed (inferred) 116 h postrelease. Note similarity to fates of fish 01, 03, and 10.	2	115.95
10	AST	Tag shed, confirmed from recapture by angler during acoustic monitoring period. Tag appears to have been shed 86 h postrelease. Note similarity to fates of fish 01, 03, and 08 in Figure 2. Data was right-censored at 800.50 h postrelease in Cox proportional hazards models.	2	19-Sept-2018
27	A	Remains alive and emigrates, confirmed by angler recapture. Note the large gaps in detection of tag transmissions at ~765–770 h, ~815–820 h, and ~840–850 h postrelease.	2	15-Oct-2021
29	AE	Appears alive until it leaves acoustic receiver array.	2	543.17
118	A	Appears alive through the end of tag transmissions.	2	813.00
120	A	Appears alive through the end of tag transmissions.	2	960.98
02	U	Very few detections, but fish appears alive when last detected.	3	0.60
09	U	Only 3 acceleration and 2 depth detections, but fish appears to have been alive when last detected.	3	3.07
14	U	Very few detections, but fish appears to have been alive when last detected.	3	1.72
15	U	Very few detections, but fish appears to have been alive when last detected.	3	1.22
18	U	Only 3 acceleration and 5 depth detections, but fish appears to have been alive when last detected.	3	0.28
48	UM	Few detections. Fish is detected at a second site after emigrating from first site. Fish appears alive when last detected.	3	11.70
50	AME	Fish is detected at a second site after emigrating from first site. Fish appears alive after leaving receiver array.	3	93.83
55	U	Very few detections, but fish appears to have been alive when last detected.	3	3.50
115	U	Very few detections, but fish appears to have been alive when last detected.	3	67.23
121	U	Very few detections, but fish appears to have been alive when last detected.	3	0.45

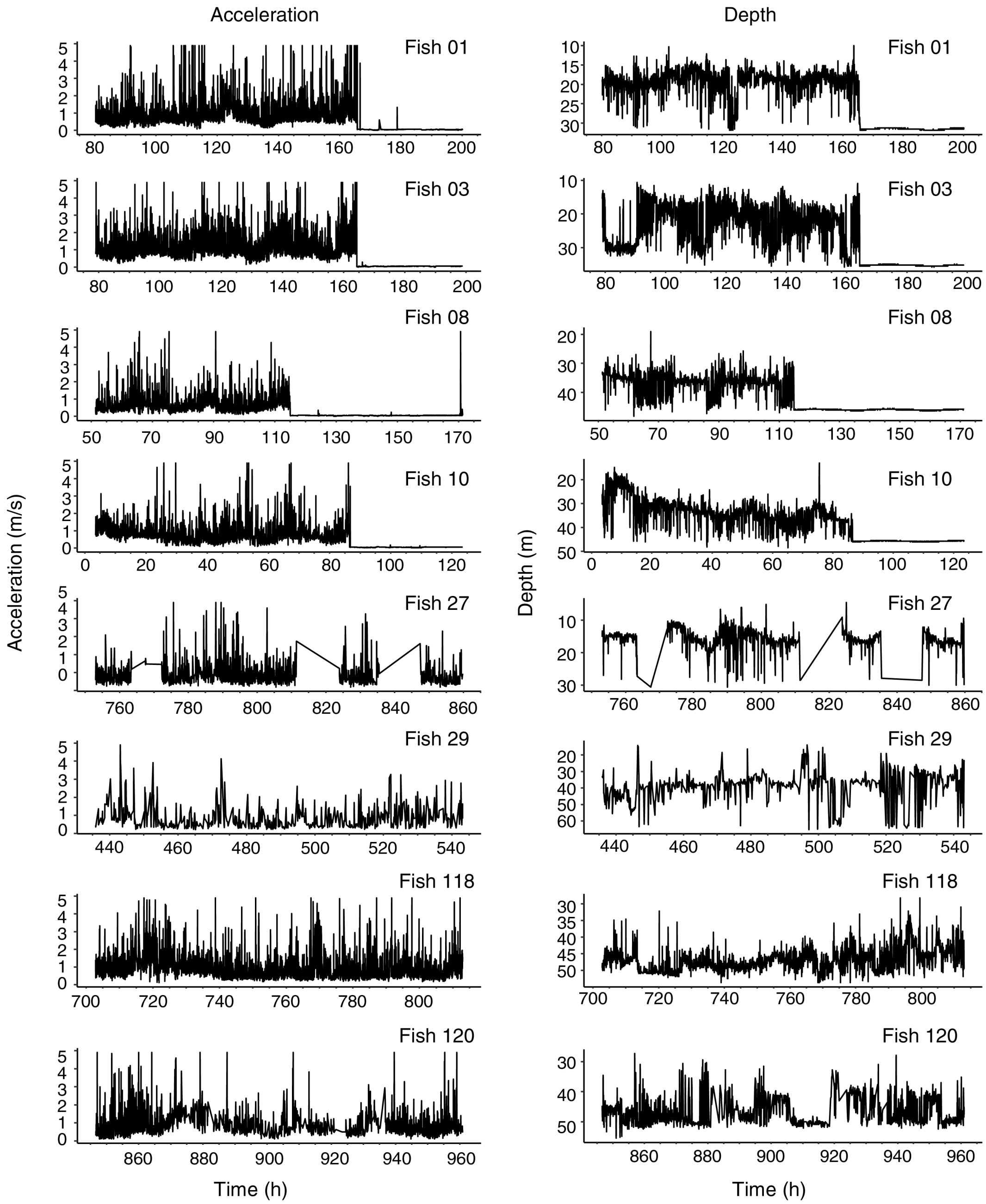

Figure 2

Acceleration and depth profiles from acoustic telemetry for tagged greater amberjack (*Seriola dumerili*) in the northern Gulf of Mexico inferred to have lived after release until the end of the battery life for their transmitters, until they emigrated from the detection range of the acoustic receiver at their release site, or until they shed their tag. Table 2 provides the rationale for the fate of each fish. Fish were caught and tagged on charter boats during 2018–2020.

For fish internally tagged in 2019 and 2020, fish length was the best predictor of survivorship, with PRM risk increasing with fish length (Table 4). The second-best model (ΔAICc: 0.67) included fishing injury in addition to fish length (Table 4). With legal length (≥864 mm FL) considered a categorical predictor, the estimated hazard ratio indicates 20 times greater PRM risk for fish of legal lengths (Table 4, Fig. 5). Legal-size fish had an estimated survival probability of 55.6% 7.6 h postrelease, and sublegal-size fish had a survival probability of 97.6% from

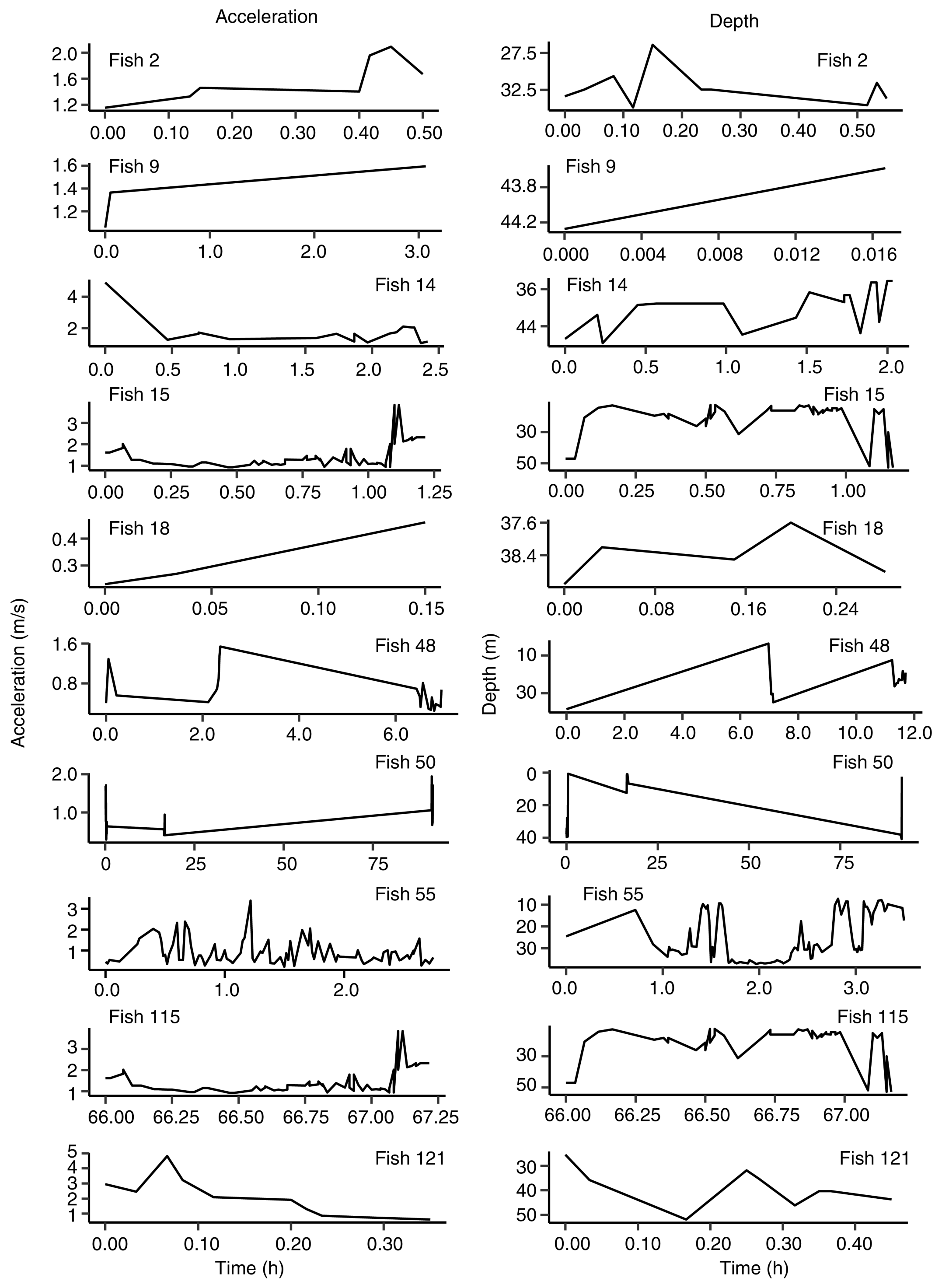

Figure 3

Acceleration and depth profiles from acoustic telemetry for tagged greater amberjack (*Seriola dumerili*) that were briefly detected with receiver arrays deployed at 16 artificial reef sites in the northern Gulf of Mexico. Fish were caught and tagged on charter boats during 2018–2020. All acceleration and depth data through the last detection of each fish are shown. The fish were inferred to be alive at the time of the last detection. All fish for which data are depicted in this figure, except fish 50, had a fate classified as *unknown* because their tags were detected for less than 68 h (the longest time observed in a case of postrelease mortality).

Table 3

Results from analysis with the Cox proportional hazards models fit to data for a subset of greater amberjack (*Seriola dumerili*) tagged with external acoustic transmitters in 2018 in the northern Gulf of Mexico (number of fish [*n*]=23). In the full model, the following predictors (P) are considered: fork length (FL); use of a descender device or not (DC); bait type (BJ), live bait or jigging; fishing injury (FI), an injury attributed to fishing gear; tagging injury (TI), an injury associated with the tagging procedure; surface temperature (ST); site depth (D); and bottom temperature (BT). Stepwise model selection based on Akaike information criterion (AIC) scores was used to determine the model with the most support. For each model, the AIC corrected for small sample sizes (AICc), the difference in AICc between the model and the best model (ΔAICc), and the likelihood ratio test statistic used to determine support of each model relative to a null model are provided. For each predictor in each model, the beta coefficient (β) and its standard error (SE) and the hazard ratio and its 95% confidence interval (95% CI) are provided. An asterisk (*) indicates that the predictor or model is significant ($P<0.05$).

AICc	ΔAICc	P	β	SE	Hazard ratio	Hazard ratio 95% CI	*P*	Likelihood ratio statistic	df	Overall *P*
Full model										
26.29	19.02							11.4	8	0.200
		FL	−0.18	43.32	0.837	1×10^{-37}–6×10^{36}	0.997			
		DC	−9.13	30,010	11,000	~0 to ∞	~1			
		D	−2.72	3232	0.066	~0 to ∞	0.999			
		BJ	−85.0	17,330	1.2×10^{-37}	~0 to ∞	0.996			
		FI	−46.9	1.2×10^{5}	4.2×10^{-21}	~0 to ∞	~1			
		TI	−3.05	1.6×10^{5}	21.2	~0 to ∞	~1			
		ST	−57.6	23,560	0.7×10^{-26}	~0 to ∞	0.998			
		BT	−31.3	81,380	2.5×10^{-14}	~0 to ∞	~1			
Second-best model										
8.13	0.86							7.9	2	0.020*
		BJ	−21.1	1.44	6.8×10^{-10}	4×10^{-11}–1×10^{-8}	<0.001*			
		ST	−76.7	5.13	5.2×10^{-34}	2×10^{-38}–1×10^{-29}	<0.001*			
Best model										
7.26	0.00							11.3	3	0.010*
		BJ	−61.3	12,170	1.2×10^{27}	~0 to ∞	0.996			
		FI	−41.7	52,850	7.7×10^{-19}	~0 to ∞	0.999			
		ST	−148	25,950	5.7×10^{-65}	~0 to ∞	0.995			
Null model										
11.30	4.17									

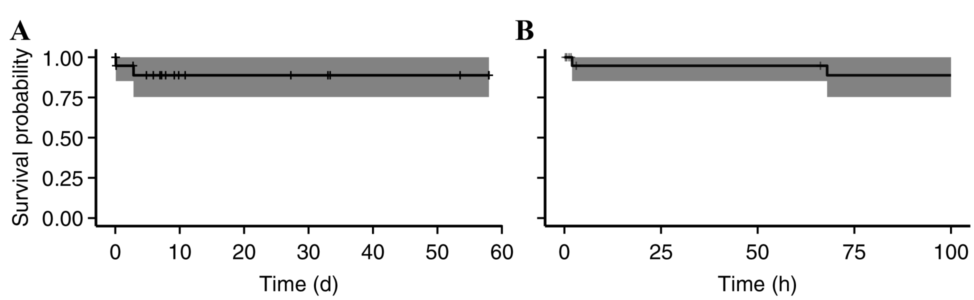

Figure 4

The Kaplan–Meier survivorship curve for greater amberjack (*Seriola dumerili*) with external acoustic tags in the northern Gulf of Mexico in 2018, (**A**) for the entire period (>50 d) for which transmitters and receivers were active and (**B**) for the first 100 h postrelease. Each cross along the curve indicates when data were censored because a fish emigrated away from acoustic receivers or shed its tag. The gray area indicates the 95% confidence interval for survival probability.

Table 4

Results from analysis with the Cox proportional hazards models fit to data for greater amberjack (*Seriola dumerili*) implanted with internal transmitters in the northern Gulf of Mexico in 2019 and 2020 (number of fish [*n*]=55). In the models, the following predictors (P) are considered: fork length (FL); use of a descender device or not (DC); bait type (BJ), live bait or jigging; fishing injury (FI), an injury attributed to fishing gear; tagging injury (TI), an injury associated with the tagging procedure; site depth (D); surface temperature (ST); and fish length (LG), with fish categorized as legal (≥864 mm FL) or sublegal size. Stepwise model selection based on Akaike information criterion (AIC) scores was used to evaluate the influence of these predictors. For each model, the AIC corrected for small sample sizes (AICc), the difference in AICc between the model and the best model (ΔAICc), and the likelihood ratio test statistic used to determine support of each model relative to a null model are provided. For each predictor in each model, the beta coefficient (β) and its standard error (SE) and the hazard ratio and its 95% confidence interval (95% CI) are provided. An asterisk (*) indicates that the predictor or model is significant (*P*<0.05).

AICc	ΔAICc	P	β	SE	Hazard ratio	Hazard ratio 95% CI	*P*	Likelihood ratio statistic	df	Overall *P*
Full model										
44.88	11.28							9.91	7	0.200
		FL	0.01	0.005	1.011	1.00–1.02	0.030*			
		DC	−0.81	1.175	0.447	0.05–4.47	0.493			
		D	0.07	0.107	1.070	0.87–1.32	0.524			
		BJ	−17.7	15,650	2.0×10^{-8}	~0 to ∞	0.999			
		FI	1.09	1.506	2.985	0.16–57.2	0.468			
		TI	−16.7	86,490	5.6×10^{-8}	~0 to ∞	1.000			
		ST	0.19	0.430	1.215	0.52–2.82	0.651			
Second-best model										
34.26	0.67							8.37	2	0.020*
		FL	0.01	0.004	1.011	1.00–1.02	0.011*			
		FI	1.80	1.351	6.021	0.43–85.1	0.184			
Best model										
33.59	0.00							6.88	1	0.009*
		FL	0.01	0.004	1.009	1.00–1.02	0.011*			
Null model										
38.40	4.81									
Model with categorical predictor: fish length (sublegal or legal)										
30.75								9.73	1	0.002*
		LG	3.01	1.120	20.22	2.25–181	0.007*			

the first minute after release to the end of the acoustic monitoring period (Fig. 5). Bottom temperature, examined for internally tagged fish for which data were available (*n*=35), was not a significant factor in PRM (Suppl. Table 7). Handling and fight times, examined for fish for which data were available (*n*=49), also were not significant factors in PRM (Suppl. Table 8).

Discussion

In this study, we found relatively high survivorship from recreational fishing methods (85%) for greater amberjack in the northern Gulf of Mexico. After accounting for all estimated sources of discard mortality, the probability of survival from PRM (89%) was lower than the probability of survival after AVM and CHM (95%). Notably, the recapture rate was relatively high (12%), underscoring the high fishing pressure in the area and likely increasing the chance of fish having repeated exposure to potential risks associated with discard mortality. In this study, fish size was the best predictor of PRM, and abiotic variables and factors associated with barotrauma (site depth) and mitigation of barotrauma (descender device use) were not associated with PRM.

Results from Cox proportional hazards modeling with data for internally tagged fish (from 2019 and 2020) indicate a substantially (20 times) increased mortality risk for legal-size fish. The survivorship curve for legal-size and sublegal-size fish indicates that, from 7.6 h to 40 d postrelease, mortality probabilities were 2% for legal-size and 44% for sublegal-size fish. Therefore, when predicting postrelease outcome, it is important to consider that fish discarded by anglers during closed seasons may include large fish (≥864 mm FL), with a higher PRM risk than smaller fish, but during the open recreational fishing periods anglers are more likely to discard sublegal-size fish when targeting legal-size fish for take.

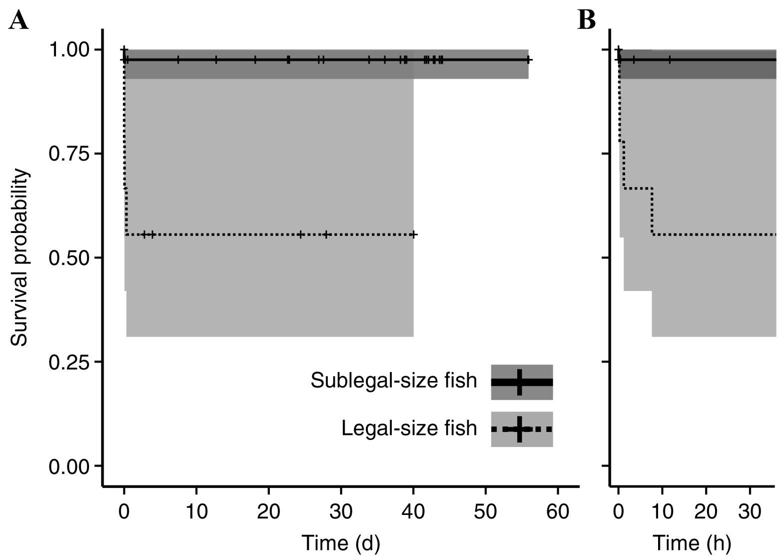

Figure 5

The Kaplan–Meier survivorship curve for greater amberjack (*Seriola dumerili*) of legal size (≥864 mm in fork length [FL]) and sublegal size (<864 mm FL) with internal acoustic tags, (**A**) for the entire period (>50 d) for which transmitters and receivers were active and (**B**) for the first 38 h postrelease. Each cross along the curve indicates when data were censored because a fish emigrated away from acoustic receivers. The gray area represents the 95% confidence interval for survival probability. Fish were caught and tagged on charter boats in the northern Gulf of Mexico in 2019 and 2020.

Having a body size smaller than legal size may reduce PRM. Results of exploratory Spearman rank correlation tests of predictor variables indicate a correlation of fight time with body size (Suppl. Table 1). This relationship is predicted because bigger fish are expected to fight harder. Although fight time was not explicitly predictive in Cox models, such a relationship may be confounded by body size. Long fight times are expected to increase stress, elevate oxygen demand, and cause exhaustion, all of which could increase discard mortality risk (including risk of PRM). Fight and handling times have been reported to have physiological effects that reduce postrelease survival in blacktip sharks (*Carcharhinus limbatus*) (Mohan et al., 2020). In our study, as expected, fish size also correlated negatively with handling time. These factors did not influence mortality in our Cox models but may be confounded by size. Effects of handling time may be less pronounced for fish discarded during normal recreational fishing compared to those in this study that involved tagging. Sublegal-size fish were more likely to be caught by jigging and to have observable fishing injuries, yet these factors did not appear to be correlated with PRM. Lastly, surface dissolved oxygen was a potential confounding variable in our study that weakly and negatively correlated with fish size in our data set, perhaps because more large fish were caught in summer in 2018 when most cases of low surface dissolved oxygen were observed in our study.

Seasonally warm temperatures in autumn (~18°C) have been considered a likely factor of PRM in a cold-temperate species, the haddock (*Melanogrammus aeglefinus*), in the Gulf of Maine (Capizzano et al., 2019). Cooler temperatures (e.g., at the surface, ~24°C in winter and spring versus 31°C in summer) have also been associated with increased postrelease survival of red snapper in the Gulf of Mexico (Curtis et al., 2015). We did not find direct support for temperature as a contributor to PRM of greater amberjack in the Gulf of Mexico. Note, however, that bottom temperature data were limited in our study for fish sampled in spring in 2019, and the sample size of observed mortalities is small (n=7). Therefore, the differential between surface and bottom temperatures and thermocline depth should be considered as potential factors in future studies.

One goal of our study was to assess the effects of 2 factors, site depth and descender device use, on PRM. We initially aimed to attach acoustic telemetry transmitters to external dart tags (Floy FH-69 tags). However, after a high rate of transmitters being shed in 2018 (56% of fish shed their tags, confirmed by the reported recapture of 17% of tagged fish), we modified our approach to monitor PRM for a longer duration after fish release. Although tag shedding was frequent in 2018, data for detections of tags that were later shed indicate survival over the first several days after release: for the 9 fish inferred to have shed tags, tags appeared to remain attached between 2.8 and 33.2 d (median: 7.2 d), and 4 recaptured fish lived beyond the study period. Only 2 fish with external acoustic transmitters died after release, and these deaths occurred between 2 h and 2.8 d postrelease. Both of these fish were from relatively shallow sites (with depths of 33 and 37 m), with one released at the surface and one released with a descender device. Therefore, there was no evidence of barotrauma-induced PRM in 2018. In 2019 and 2020, we placed transmitters in the posterior end of the coelomic cavity and did not attempt to vent the swim bladder. Although no ruptured swim bladders were observed during tag implantation, it is possible that some swim bladder gas was inadvertently released. For fish tagged in 2019 and 2020, there was no evidence that site depth increased mortality. Use of descender devices did not appear to mitigate PRM risk, but they did not add mortality risk, which might have been expected from predation of tethered fish on descent or from increased handling time when the descender device was used.

Susceptibility to barotrauma varies among species and capture depths (Jarvis and Lowe, 2008). Species that ascend rapidly and undergo diel depth migrations are predicted to resist depth-related trauma. In a recent study in which discard mortality in 2 species, the red snapper and gray triggerfish (*Balistes capriscus*), was examined, descender device use was found to be associated with a decrease in PRM for red snapper but not for gray triggerfish (Bohaboy et al., 2020). In addition, barotrauma risk increases with capture depth. In a recent study on PRM of greater amberjack at 2 sites that varied in depth, site depth was found not to predict survivorship (Jackson et al., 2018). In the Jackson et al. (2018) study, fish were vented prior to release, given that previous observations (Murie and Parkyn[2]) indicate turgidity in swim bladders of fish caught at depths greater than 45 m. Therefore, the potential for capture depth as a factor in postrelease survivorship could still exist without mitigation of venting. Murie and Parkyn[2] noted that anatomy of greater amberjack in the region of the pectoral girdle lacerates near the medial supracleithrum upon depth-related swim bladder expansion and allows bubble release. This "self-venting mechanism" (Murie and Parkyn[2]), however, could still pose injury risk to released fish.

In a mark-recapture study of greater amberjack that were collected at depths of 15–95 m off the Atlantic coast of the southeastern United States and were vented prior to release, no trends in recapture rates related to site depth were observed (i.e., no increased mortality occurred at sites where barotrauma would be predicted) (McGovern et al., 2005). In our study (in which fish were captured at depths <65 m), it was not known if fish mitigated barotrauma by self-venting or if barotrauma simply was not a factor. It was also not known if greater amberjack faced higher PRM risk at capture sites with depths greater than 64 m. Greater amberjack occuppied a wide depth range throughout the day. Even at deep reef sites (>64 m), fish may be hooked at shallower depths and require less compensation for luminal gas expansion of the swim bladder than would be expected if they were hooked near the seafloor.

Fish that succumbed to PRM in this study tended to die quickly (median: 1.2 h postrelease; range: 0.02–68.00 h postrelease). Sixteen acoustically tagged fish (20.5%) were not detected for more than 68 h (median: 0.2 h; range: 0.00–3.50 h). The fate of these fish remains a question, although no evidence of predation existed. Emigration immediately following release is often reported from studies in which passive acoustic telemetry was used, and as a result, the fates of many fish remain unknown, leaving the potential for higher PRM (Topping and Szedlmayer, 2011; Curtis et al., 2015). Two fish in our study were detected only once at the reef where they were tagged and released, and they were subsequently detected at a reef 4.5 km away. Therefore, initial emigration is clearly not always associated with mortality. In our study, 16% of acoustically tagged fish that were detected alive ≥68 h postrelease moved between study sites with acoustic receivers, highlighting that movement of greater amberjack among reefs is relatively common. Additional emigration in this study appeared associated with cyclonic storms. Six fish in 2020 were not detected until 7–12 d after release. In addition, 11 fish moved to different reefs that happened to have acoustic receivers, and 3 of those fish did not return to the reef where they were tagged and released. Therefore, having acoustic receivers in multiple locations helped prevent underestimation of postrelease survival and should be a consideration in studies of discard mortality in mobile reef fishes.

Total discard mortality in our study, although comparable, was notably higher than the estimate for recreational fisheries (13.5% versus 10%, respectively) in the recent stock assessment of greater amberjack in the Gulf of Mexico (SEDAR, 2020). For greater amberjack in our study, PRM was the greatest component of discard mortality (AVM, CHM, and PRM). Discard mortality is an important component of total fishing mortality, and robust estimates of this rate are essential for effective stock management.

Conclusions

Results of this study, in which a broad range of abiotic factors, such as site depth, use of a descender device, and fish length were examined, indicate that fish size presents the greatest risk for PRM of greater amberjack at sites with depths ≤64 m. Our study followed up previous work by Jackson et al. (2018) that examined discard mortality over a narrower depth range for fish that were vented prior to release. In our study, with fish released at depths of 29–64 m, use of a descender device did not appear to influence PRM. In contrast to what occurred in the Jackson et al. (2018) study, we found that PRM risk increases with fish size. These findings point to important management considerations, given that the release of small individuals (<864 mm FL), required by restrictions on the size of fish that can be kept, appears to carry less PRM risk than the discard of legal-size fish. With our Cox proportional hazards model with fish size analyzed as a non-discrete variable, we estimated that mortality increases by 0.9% (hazard ratio: 1.009) per 1 mm increase in FL, a finding that should be considered when proposing changes to size regulations for greater amberjack in the northern Gulf of Mexico.

Resumen

El manejo de la pesca recreativa del medregal (*Seriola dumerili*) en el golfo de México incluye regulaciones de talla y temporadas de veda. La temperatura del agua, la salinidad, los tiempos de forcejeo y manipulación, así como el barotrauma pueden influir en la supervivencia de los peces liberados. Examinamos la mortalidad y el comportamiento

[2] Murie, D. J., and D. C. Parkyn. 2013. Preliminary release mortality of Gulf of Mexico greater amberjack from commercial and recreational hand-line fisheries: integration of fishing practices, environmental parameters, and fish physiological attributes. Southeast Data, Assessment, and Review SEDAR33-DW29, 13 p. [Available from website.]

posterior a la liberación utilizando telemetría acústica de los movimientos de 78 peces, monitoreados hasta 58 días a través de 3 esfuerzos de muestreo en 2018, 2019 y 2020 en un gradiente de profundidad de 29–64 m. Para evaluar los dispositivos de descenso como herramienta de mitigación, asignamos peces a 2 tratamientos: liberación en superficie sin ventilación de la vejiga natatoria y liberación con un dispositivo de descenso. Se utilizaron modelos de riesgos proporcionales de Cox para evaluar los efectos de la profundidad del lugar, el tratamiento de liberación, el tipo de carnada (señuelo o carnada viva), las lesiones por pesca, las lesiones por marcado, los tiempos de forcejeo y manipulación, las temperaturas de la superficie y del fondo, y la longitud de los peces. No se encontró una asociación positiva entre el riesgo de mortalidad y la profundidad del sitio de liberación, como se esperaría del barotrauma, ni una mayor supervivencia de los peces liberados con un dispositivo de descenso. El modelo mejor sustentado consideró únicamente la longitud de los peces como factor de mortalidad tras la liberación; los peces de tamaño legal (≥864 mm de longitud furcal) tuvieron un riesgo de mortalidad 20 veces mayor que los peces más pequeños. Nuestros resultados indican que, debido a las restricciones de tamaño, los peces de talla inferior a la legal liberados se enfrentan a un riesgo de mortalidad mucho menor que los peces de talla legal.

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