

# Under pressure: Comparing *in situ* and boat tagging methods using time-to-event analyses

Jessica A. Keller (✉ [jakeller@coastal.edu](mailto:jakeller@coastal.edu))

Florida Fish and Wildlife Conservation Commission <https://orcid.org/0000-0002-6782-1917>

Danielle Morley

Florida Fish and Wildlife Conservation Commission

Jennifer Herbig

Florida Fish and Wildlife Conservation Commission

Paul Barbera

Florida Fish and Wildlife Conservation Commission

Michael W. Feeley

National Park Service

Alejandro Acosta

Florida Fish and Wildlife Conservation Commission

---

## Telemetry case report

**Keywords:** In situ tagging, acoustic telemetry, survival analysis

**Posted Date:** January 7th, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-56006/v2>

**License:**  This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

---

**Version of Record:** A version of this preprint was published at Animal Biotelemetry on January 27th, 2021. See the published version at <https://doi.org/10.1186/s40317-021-00229-z>.

# Abstract

**Background** With the increase in telemetry studies over the past decade, improving understanding of how different tagging methods influence fish survivorship is critical. By examining the effects of tagging methods, we can maximize the information gained from telemetry studies. Mortality resulting from internally tagging fish on a boat may be due to barotrauma injuries, increased stress from prolonged handling times, or predation after fish have been released back into the water. Conducting in situ internal acoustic tagging at depth of capture completely removes barotrauma stresses and simplifies the release method, which may improve fish survival. In this study, we used 8 years of acoustic tagging data to determine if the tagging method (in situ versus on the boat) influenced fish survivorship and evaluated the role of other tagging variables. **Results** At 6 days after tagging, Kaplan–Meier survival curves revealed that the survival probability of fish tagged on the boat was 66% while survival probability of fish tagged in situ was 90%. Tagging method was the only variable to significantly affect survival probability based on Cox proportional hazards models, with fish tagged in situ ~75% less likely to have an “event” (mortality, tag loss, or emigration) compared to fish tagged on the boat at both 4 and 6 days after tagging. Examining tagging methods separately, handling time only marginally influenced survival probability of boat-tagged fish and no variables had a significant effect on survival of in situ tagged fish. **Conclusions** In this study, tagging method was the only variable to significantly affect survival of internally tagged fish. Implanting internal acoustic tags in situ is not a practical method for every species and for every environment, but given the increased fish survivorship demonstrated here, we strongly suggest it be considered as the preferred tagging methodology where applicable.

## Background

Acoustic telemetry has become a widely accepted method for collecting animal movement data in the marine environment (Hussey et al. 2015). Data collected from acoustically tagged fish can be used to investigate a wide variety of biological and ecological questions. For example, acoustic telemetry data have provided answers to broad ecological questions, such as revealing previously unknown migration patterns for certain species (Feeley et al. 2018, Pratt et al. 2018) and have also been used to answer more localized questions, such as patterns of habitat use in a specific location (Herbig et al. 2019, Keller et al. 2020). Although acoustic telemetry studies have been rapidly increasing in number over the past 20 years (Crossin et al. 2017), there are far fewer studies that examine the influence of tagging methodology on acoustic telemetry results (Dance et al. 2016). This information is needed because the physical act of tagging a fish can affect the outcome of the tagging event, potentially change the behavior of that fish, and even influence the interpretation of results.

In traditional mark/recapture studies, external tags are inserted into the dorsal musculature. Traditional mark/recapture studies are a cost-effective method of tagging animals, but these studies may provide only limited spatial information, require the recapture of tagged fish, and often have low success rates (Lucas and Baras, 2000). To overcome some of these limitations, researchers use more advanced tags, such as acoustic tags. While externally attaching acoustic tags has been accomplished through a wide

array of techniques, these tags can be quickly shed, causing a truncation of data collection (Jepsen et al. 2015). An alternative method of acoustic tagging that increases tag retention is internally inserting the tag, usually through surgery (Wagner et al. 2011). However, internally tagging a fish on a boat may increase the chances of fish mortality post-release due to stress from barotrauma, changes in water and air temperature, prolonged fish handling, or the amount of time the fish spends at the surface (Williams et al. 2015). Even with survival from the tagging surgery, there is still the potential for physical trauma (bruising, bleeding, or acute damage) or physiological disturbance (changes affecting gasses, blood, and pH levels) associated with stress from capture or mishandling (Skomal 2007, Gallagher et al. 2014, Wilson et al. 2014).

Additionally, newly tagged fish may be more susceptible to predation, especially if the fish must travel through the water column before reaching a protective habitat (Piraino and Szedlmayer 2014). Acoustic tagging release method experiments have demonstrated that fish descender devices, which return fish to depth, can increase fish survivorship (Bohaboy et al. 2019), but devices that both return a fish to depth and protect against predators (e.g., cages) are best for increased fish survivorship (Piraino and Szedlmayer 2014; Williams et al. 2015). However, a review of barotrauma treatment (venting and descending devices) in catch-and-release studies revealed inconsistency about which method is most beneficial in reducing or treating barotrauma, likely because of differences in environmental or species-specific physiological variables and differences in assessment methods (Eberts and Somers 2017).

All tagging methods have the potential to cause health issues for the fish, so decreasing the risk of health issues should be a priority when planning a tagging project. In the case of acoustic telemetry, it is often difficult to determine the fate of fish when they are no longer detected. While effects of the tagging procedure can cause mortality through physical trauma, the fish may also experience mortality via predation or fishing pressure, lose the transmitter, or immediately emigrate from the tagging area. A tagging procedure that minimizes stress to fish may also minimize the risk of these events by shortening the surgery recovery period and reducing the risk of both predation and emigration by releasing the fish directly into the natural sheltering habitat.

We suggest consideration of conducting *in situ* internal acoustic tagging of fish at depth of capture to remove barotrauma stressors and simplify the release method. Tagging fish *in situ* with acoustic transmitters at the same depth as capture and release has become more popular as studies have shown the negative effects of barotrauma on fish survival (Rummer and Bennett 2005; Rundershausen et al. 2014). Externally tagging fish *in situ* has been reported for multiple studies (Atkins et al. 2014, Balázs et al. 2015, Sigurdsson et al. 2006), and internally tagging fish *in situ* has become more common. For example, Starr et al. (2000) captured deep-sea greenspotted rockfish (*Sebastes chlorostictus*) at depths between 100–200 m, brought them up to 20 m where they were internally tagged, then lowered them back down to depth and released them. Lindholm et al. (2005) used saturation diving from the Aquarius underwater laboratory in the Florida Keys to internally tag fish, and Tuoy et al. (2015) used closed circuit rebreathers. Recently, Feeley et al. (2018), McCallister et al. (2018), Bryan et al. (2019), and Keller et al. (2020) all describe internally tagging reef fish *in situ*.

While there has been comparison of discard mortality between *in situ* and boat-tagged fish using external tags (Rudershausen et al. 2014), to our knowledge there has been no study directly comparing the results of internally tagging fish on a boat versus *in situ*. In this study, we use 8 years of acoustic tagging data and our personal experiences with surgically implanting transmitters in fish to examine 1) the influence of tagging method (*in situ* versus on the boat) on detectability of a fish post-surgery and 2) the effects of other tagging variables (e.g., handling time and surgeon experience) that might influence detection probability after release..

## Methods

### Fish tagging

Fourteen species of groupers (Serranidae) and snappers (Lutjanidae) were internally tagged with acoustic transmitters (tag life: 417-1825 days) from 2008–2016 by Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute staff in the Florida Keys and Dry Tortugas, Florida (Fig. 1). During the 8 years of tagging examined in this study, fish were captured with hook and line or underwater baited traps. Hook-and-line captured fish were brought to the boat where they were surgically implanted with acoustic transmitters and returned to depth by divers. Fish caught in underwater traps (times between checking and rebaiting traps were approximately 1-12 hours) had their tags inserted *in situ* by a team of divers. A detailed description of boat and *in situ* tagging and acoustic array designs can be found in Feeley et al. (2018), Herbig et al. (2019), and Keller et al. (2020).

The surgical procedures during boat and *in situ* tagging were similar with the exception that anesthesia (AQUI-S, 50% isoeugenol; aqui-s.com) was not used *in situ*. We noticed that fish were calm once they were turned ventral side up and their behavior was similar to that of fish that had been anesthetized. Tonic immobility is commonly used as an alternative to chemical-based anesthesia for surgical implantation in elasmobranchs (Kessel and Hussey 2015, Sloan et al. 2019) and after a few initial efforts, we realized that use of chemical-based anesthesia for tagging fish *in situ* was not necessary or beneficial and did not allow a quick and immediate release of the fish after surgery was completed. Acoustic tagging procedures in this study were approved by Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute and every effort was made to follow accepted standards and ensure the ethical treatment of captured fish.

Fig. 1 Fish tagging locations and acoustic receiver arrays in the Lower Florida Keys and Dry Tortugas. Fish and Wildlife Research Institute receivers are represented as circles and Integrated Tracking of Aquatic Animals in the Gulf of Mexico receivers are represented as triangles. Bathymetry data in the subplots shows depth as a gradient from light (shallower) to dark (deeper) blue (0 – 132 m). Receiver location depths ranged from 3 – 43 m. Receivers depicted on this map were deployed during different times from 2008 – 2018, depending on the study. Details regarding receiver timing can be found in Feeley

et al 2018, Herbig et al 2019, and Keller et al 2020. Bathymetry data is a part of the Florida Keys National Marine Sanctuary Digital Atlas (Taylor et al. 2018).

## Tagging variables

During both tagging methods, the following tagging variables were recorded: species, total length of fish (TL), depth of capture, tagging location, handling time, tagging time, and name of the person performing the surgery. Tagging time was the total time of the tag implantation surgery, while handling time was either the total time the fish was on the boat or total time the fish was handled underwater. Handling times on the boat included the time it took for fish to show effects of anesthesia before surgery and time for the fish to regain its equilibrium and display other signs of recovery before being released by divers. "Fight" times for fish caught via hook and line were not recorded, so analyses examined only the amount of time the fish was on the boat. Tagging location was the general location of the tagging, either the Lower Florida Keys or the Dry Tortugas (Fig. 1), and was included to account for any environmental differences between locations. Habitat types within the two tagging locations were similar and contained low to mid relief continuous coral reefs and patch reefs.

The family name of fish, either Serranidae or Lutjanidae (n=2), was also included as a covariate to examine differences in survival based on physiological differences between taxonomic groups but to avoid overparametrizing the models because of the high number of species (n=14). Depth of capture was also recorded, though for fish tagged on the boat, the depth recorded was that of the seafloor as it was not possible to determine the exact depth in the water column the fish was first caught on hook and line. Total length of fish at time of capture was transformed into a two-factor variable called "fish size" to compare small and large fish without the confounding factor of fish family. Mean total lengths were determined separately for each family and used as a threshold value. – Fish were designated as "small" if their length was below this value for the respective family and "large" if their length was equal to or greater than this value.

The variable month was used to examine whether time of year influenced the risk of disappearance. Water temperature varies throughout the year and could affect a fish's health during surgery and after release. Fish behavior (e.g. courtship/spawning behaviors) also varies throughout the year and between families, which can influence the likelihood of a fish emigrating from the area.

To determine if the tagging experience of the surgeon had an influence on the risk of disappearance, a variable called "surgery count" was created. This variable was determined by ordering the tagging data by date and named surgeon (regardless of tagging method) for all fish tagged in this study that had surgeon name recorded. This information was used to assign each fish a surgery count number based on how many surgeries the surgeon had previously completed. For example, surgery count had a value of one if it was the first fish the surgeon had ever tagged or a value of 17 if it was the 17<sup>th</sup> fish a surgeon had tagged. The data included in this study includes all, or nearly all, of each surgeon's internal tagging

experience until the end of the study period or until the person left the agency. A few surgeons had some prior experience internally tagging fish but were unable to accurately quantify their experience, so all surgery counts in this study started with a value of 1.

## Data validation

Before inclusion in analyses, fish that did not have complete tagging procedure data were excluded from the dataset. Detection data was then validated for fish included in analyses. To validate detection data, fish with only one detection were excluded because a single detection could be caused by collisions or noise and is not considered reliable (Simpfendorfer et al. 2015). Detections from fish that were detected only on one receiver were examined to determine whether detections were the result of normal fish activity or from a tag loss or mortality event. Consistent detections regardless of hour or day or a pattern of higher detections during a particular diel period could be due to a tag sitting on the seafloor with changes in environmental conditions throughout the day influencing transmission success. If detections were suspected to be due to a tag sitting on the seafloor, those detections were removed.

## Time-to-event analysis

We used time-to-event analysis (also called survival analysis) to compare the risk of tagged fish disappearing from the receiver array between the two tagging methods. The Cox proportional hazards model is a common analytical method for assessing what variables cause the most risk to survival in discard mortality and delayed mortality studies (Curtis et al. 2015, Runde et al. 2019, Bohaboy et al. 2019). We used the Cox proportional hazards model to examine which tagging variables most influenced the risk of fish disappearing from the receiver array. In this study, acoustic telemetry data could only provide presence/absence data, making difficult to determine mortality (i.e. an end of detections could be due to emigration, predation, harvest, etc.). As presence/absence data is unable to determine mortality, time-to-event analyses examined the risk of fish disappearing from the receiver array for the final time (i.e. the date of last detection) rather than risk of mortality.

Before covariates were included in the model, they were tested for covariance with other variables via a correlation matrix and Pearson's test of correlation. All categorical variables were two-factored and were changed to binary outputs to allow for point-biserial correlation. Variables that had statistically significant correlation with each other ( $p < 0.05$ ) were not included in the same hazards model.

The influence of tagging procedure variables on the risk of disappearance from the array was examined at two different time periods, 4 and 6 days after surgery. The two time periods were chosen based on literature suggesting 4–6 days post-surgery to be a time frame when events (mortality, tag loss, or emigration) are most likely due to tagging artifacts (Topping and Szedlmayer 2011; Piraino and Szedlmayer 2014, Tuohy et al. 2015). Any shorter time frame may miss delayed effects from tagging and longer time frames increase the chance of mistaking behavioral events for those related to the tagging procedure. We decided to examine risk of disappearance at both 4 and 6 days after tagging to determine if there were any differences between these two time frames. For each fish, the last day of its detection

was used to calculate the number of days it was present before it disappeared from the array. For example, if a fish was last detected 5 days after the tagging procedure, it was marked as having an event at day 5.

If a fish was detected past the 4- or 6-day mark, the number of days it was considered present was truncated to 4 or 6 days, depending on which time frame was used for analysis. For example, if a fish was not detected on day 6, but was detected more than once on day 50, it was considered alive and present on day 6. Long gaps in detections may have occurred as fish often left receiver coverage area before returning, but all fish included in this study were regularly detected and did not display suspicious data such as getting detected the first few days after tagging and only having one subsequent detection a year later.

To increase the chances of determining the most accurate activity level of a tagged fish, detection data from acoustic receivers deployed throughout the Florida Keys during 2008-2018 (not just the receivers in the array where the fish was tagged), were included to determine a fish's status. Detection data came from receivers owned by FWRI and the Integrated Tracking of Aquatic Animals of the Gulf of Mexico (iTAG) network (Lowerre-Barbieri et al. 2017; [Figure 1](#)).

To visually compare the probability of presence and number of disappearances between the two tagging methods, Kaplan–Meier survival curves were created using the “survival” package (Therneau 2015) in R (R Core Team 2019). To examine what factors were most influential on risk of disappearance, Cox proportional hazards models were calculated at both 4 and 6 days after tagging also using the “survival” package. Model selection started with the full model using all covariates that were not correlated with tagging method (the main variable of interest) or each other. The best-fitting model was chosen through a backwards stepwise search, starting with the full model, and model selection based on lowest Akaike information criterion with a correction for small sample size (AICc) using the “MASS” package (Venables and Ripley 2002). Beyond the initial Cox proportional hazards model examining the influence of tagging method on risk of disappearance, two secondary hazards models were performed to assess which variables influenced risk of disappearance for 1) fish tagged on the boat and 2) fish tagged *in situ*.

Hazard ratios from the hazards model provide information on the covariates' effects on risk of disappearance. Hazard ratios above a value of 1 indicate an increase in risk of disappearance compared to a reference point, whereas a value below 1 indicates a reduction in risk. For categorical covariates, a hazard ratio less than 1 is the proportional reduction in risk compared to the reference level and vice versa. For continuous covariates, a hazard ratio less than 1 is the proportional reduction in risk of a disappearance as the value of the covariate increases by 1 unit. A hazard ratio greater than 1 is the proportional increase in risk of a disappearance as the value of the covariate increases by 1 unit. The farther away a hazard ratio is from 1, the greater the influence of that covariate. A hazard ratio near 1 means that covariate has a marginal effect on the risk of disappearance (and thus the probability of presence) while a hazard ratio at 1, or a confidence interval that crosses 1, has no effect on the risk of disappearance (Kleinbaum and Klein 2012).

Independence between residuals and time is an assumption of the proportional hazards model (Kleinbaum and Klein 2012) and was checked in all models by testing the correlation between scaled Schoenfeld residuals and time using the “cox.zph” function in the “survival” package. A statistically significant correlation of Schoenfeld residuals and time rejects the null hypothesis and violates the assumption of the proportional hazards model.

## Results

Of the fish tagged from 2008–2016, 194 were internally tagged grouper and snapper. Fish with incomplete tagging information ( $n=87$ ) were excluded and two fish were excluded from analyses because they had only a single detection. Data from fish detected at only one location were examined, but no fish had continuous, consistent detection patterns suspected of resulting from a discarded tag. Receivers in both the Lower Keys and Dry Tortugas arrays were often spaced farther apart to try to maximize coverage area and therefore most receivers did not have overlapping coverage. Since most fish detected at a single location were groupers or small snappers that were not expected to make long-distance movements, smaller movements could have been missed because of spacing between receivers. Therefore, since examined data did not display suspicious patterns, no fish detected at only a single location was excluded from analyses. In total, 105 fish from 14 different species were included in analyses (35 boat-tagged and 70 *in situ* tagged; Table 1).

The mean total length was  $57.0 \pm 1.4$  cm (mean  $\pm$ SE) for Lutjanidae and  $64.6 \pm 1.7$  cm for Serranidae. These values were used to determine whether the variable of “fish size” was “small” or “large”. Mean handling time and depth of capture varied between tagging method, but mean tagging time was similar (Table 2).

*In situ* tagged fish had a lower probability of disappearing from the array compared to fish tagged on the boat, based on Kaplan–Meier survival curves (Fig. 2). Six days after tagging, the probability of presence of fish tagged on the boat was only 66% while the probability of presence of fish tagged *in situ* was 90%. The null hypothesis that there was no difference between the two methods in the probability of presence from day of tagging to 6 days after tagging was rejected by a log-rank test ( $p = 0.002$ ).

Fig. 2 Kaplan–Meier survival curves showing probability of presence for fish tagged *in situ* and on the boat from day of tagging to 6 days afterward. Shaded areas indicate 95%

confidence interval for the survival curves. A risk table shows the number of individual fish and percentage of total fish still detected in 2-day bins for both tagging methods.

Table 1. Number of fish in time-to-event analyses by species, tagging method, and size.

<b>Tagging method and fish species</b>	<b>Total fish</b>	<b>Small</b>	<b>Large</b>
<b>Boat-tagged</b>	<b>35</b>	<b>19</b>	<b>16</b>
Black grouper, <i>Mycteroperca bonaci</i>	8	5	3
Gray snapper, <i>Lutjanus griseus</i>	1	1	-
Mutton snapper, <i>Lutjanus analis</i>	14	2	12
Red grouper, <i>Epinephelus morio</i>	1	1	-
Yellowfin grouper, <i>Mycteroperca venenosa</i>	1	-	1
Yellowtail snapper, <i>Ocyurus chrysurus</i>	10	10	-
<b>In situ tagged</b>	<b>70</b>	<b>28</b>	<b>42</b>
Black grouper, <i>Mycteroperca bonaci</i>	17	6	11
Dog snapper, <i>Lutjanus jocu</i>	6	-	6
Gag, <i>Mycteroperca microlepis</i>	2	-	2
Gray snapper, <i>Lutjanus griseus</i>	8	8	-
Mutton snapper, <i>Lutjanus analis</i>	13	-	13
Nassau grouper, <i>Epinephelus striatus</i>	8	6	2
Red Hind, <i>Epinephelus guttatus</i>	1	1	-
Rock Hind, <i>Epinephelus adscensionis</i>	1	1	-
Scamp, <i>Mycteroperca phenax</i>	4	3	1
Schoolmaster, <i>Lutjanus apodus</i>	1	1	-
Yellowfin grouper, <i>Mycteroperca venenosa</i>	8	1	7
Yellowmouth grouper, <i>Mycteroperca interstitialis</i>	1	1	-
<b>Total</b>	<b>105</b>		

Table 2. Mean values  $\pm$  SE for handling time, tagging time, and depth between boat and *in situ* tagging methods.

	<b>Handling time (min)</b>	<b>Tagging time (min)</b>	<b>Depth (m)</b>
<b>Boat-tagged</b>	72.17 $\pm$ 6.02	6.37 $\pm$ 0.35	13.29 $\pm$ 2.14
<b>In situ tagged</b>	9.30 $\pm$ 0.31	6.96 $\pm$ 0.27	24.61 $\pm$ 0.94

Fish size, tagging time, and surgery count were the only variables not significantly correlated with tagging method (the main variable of interest) or each other and therefore were the only variables included in the initial Cox proportional hazards models (Fig. 3). Variables that were significantly correlated with tagging method or with each other could not be included in the hazards model without compromising model results. Because of correlation among variables, model selection using backward stepwise selection started with a full model including only tagging method, tagging time, and fish size. Backward

stepwise model selection found the best fitting hazards model (based on lowest AICc) at the 4-day mark to include tagging method and tagging time as covariates, while at the 6-day mark, tagging method was the only variable in the best fitting model (Table 3).

Fig. 3 Pearson correlation coefficients for all covariates for all fish tagged. Size and color of dots indicate strength and direction of correlation. Boxes without dots indicate no statistically significant correlation ( $p > 0.05$ ). Boxes with a thick black outline indicate the variables included in the full model.

Table 3. Cox proportional hazards models with AICc stepwise model ranking for both 4 and 6 days after tagging. All models include probability of presence as the dependent variable and list independent variables included in each individual model. All fish were included in these models (n=105). P-values are from the log rank test.

Days after tagging	Hazards model	AICc	$\Delta$ AICc	$\chi^2$	df	p
4	Method + Tagging time	131.19	0.00	11.11	2	0.004
	Method	131.47	0.28	8.98	1	0.003
	Method + Tagging time + Surgery count	131.72	1.53	11.92	3	0.008
	Method + Tagging time + Fish size + Surgery count	134.83	3.64	11.12	3	0.010
	Null	137.52	6.33			
6	Method	166.68	0.00	9.78	1	0.002
	Method + Tagging time	167.58	0.90	10.82	2	0.004
	Method + Tagging time + Fish size	169.68	3.00	10.85	3	0.010
	Method + Tagging time + Fish size + Surgery count	171.83	5.15	10.87	4	0.03
	Null	173.38	6.70			

Hazards model results for the best fitting models indicate that fish internally tagged *in situ* were 76% less likely (one minus the hazard ratio) to disappear from the array 4 days after tagging and 75% less likely to disappear 6 days after tagging compared to fish tagged on the boat (Table 4). Tagging time was also included in the best-fitting 4-day model, though the 95% confidence interval spanned 1, indicating there was no effect. For all covariates in both best-fitting models, the proportional hazard assumption was supported by a nonsignificant relationship between scaled Schoenfeld residuals and time. To visually compare each covariate's risk to fish survival, hazard ratio forest plots were

produced from the full and best-fitting models, and plots for 4 days after tagging are shown as an example (Fig. 4a and 4b).

Table 4. Cox proportional hazards models results for the best-fitting model at 4 and 6 days after tagging. For the categorical covariates, the hazard ratio is the proportion of risk compared to the reference covariate. For the continuous covariates, the hazard ratio is the proportion of risk with an increase of 1 unit (e.g., 1 min). A variable with a hazard ratio close to a value of 1 has a marginal effect and a confidence interval (CI) spanning 1 has no effect on hazard. All models include probability of presence as the dependent variable and list independent variables included in the best-fitting models. P-values are from the log-rank test.

Days after tagging	Factor	Coefficient	SE	Hazard Ratio	95% CI	<i>p</i>
4	Tagging method: Boat	Reference	-	-	-	-
	Tagging method: <i>in situ</i>	-1.437	0.549	0.237	0.081 - 0.696	0.009*
	Tagging time	-0.190	0.122	0.827	0.650 - 1.051	0.120
6	Tagging method: Boat	Reference	-	-	-	-
	Tagging method: <i>in situ</i>	-1.378	0.476	0.252	0.099 - 0.641	0.004*

Fig. 4 Forest plots showing covariate hazard ratios at 4 days after tagging for the a) full model and b) best-fitting Cox proportional hazard model. Hazard ratios and 95% confidence intervals for each covariate are shown with p-values listed on the right-hand side of the plots with asterisks indicating significance. Hazard ratio values less than 1 (represented by the dotted line) indicate a reduction in risk of disappearance from the array while values greater than 1 indicate increased risk of disappearance. Covariates with hazard ratios close to 1 have a marginal effect on hazard and confidence intervals crossing 1 indicate no significant effect.

Pearson correlation coefficients were also calculated for all covariates when splitting the data into fish tagged on the boat and fish tagged *in situ*. Handling time and depth were the two main covariates of interest. However, since these two covariates were correlated for fish tagged on the boat (Fig. 5a), they could not be included in the same hazards model. As a result of these correlations, two full models were created for fish tagged on the boat:

1) one with depth and all variables not correlated with each other, and 2) one with handling time and all variables not correlated with each other.

For *in situ* tagged fish, handling time and depth were not correlated with each other, but depth was correlated with fish size and both depth and handling time were correlated with month (Fig. 5b). Three full models were created for *in situ* tagged fish: 1) one with handling time, depth, and all other variables not correlated with each other, and 2) one with handling time, fish size, and all other variables not correlated with each other, and 3) one with month and all non-correlated variables.

Fig. 5 Pearson correlation coefficients for all covariates for a) boat-tagged and b) *in situ* tagged fish. Size and color of dots indicate strength and direction of correlation. Boxes without dots indicate no statistically significant correlation ( $p > 0.05$ ).

Handling time was the only covariate included in the best fitting model for boat-tagged fish at 4 days after tagging (Table 5). At 6 days after tagging, both handling time and family were included in the best-fitting model. Handling time was significant in both best-fitting models; however, the hazard ratio was very close to 1, meaning the effect of handling time on hazard of disappearance was marginal (Table 6). A hazard ratio of 2.55 for family Serranidae in the 6-day model indicated an increase in risk compared to Lutjanidae. However, this covariate had a wide confidence interval that crossed 1, indicating no significant effect of hazard and a somewhat unreliable point estimate (Kleinbaum and Klein 2012). For all covariates in both best-fitting models, the proportional hazard assumption was supported by a nonsignificant relationship between scaled Schoenfeld residuals and time.

Table 5. Cox proportional hazards models examining probability of presence for fish tagged on the boat (n=35) at both 4 and 6 days after tagging. Models are ranked by AICc values. All models include probability of presence as the dependent variable and list independent variables included in each individual model. P-values are from the log rank test.

Days after tagging	Hazards model	AICc	$\Delta$ AICc	$\chi^2$	df	p	
4	Handling time	66.00	0.00	4.17	1	0.04	
	Handling time + Family	67.08	1.08	5.76	2	0.06	
	Tagging time	68.13	2.13	2.37	1	0.1	
	Null	68.26	2.26				
	Handling time + Tagging time + Family	68.60	2.60	6.96	3	0.07	
	Tagging time + Surgery count	69.12	3.12	3.79	2	0.2	
	Tagging time + Surgery count + Family	70.64	4.64	5.06	3	0.2	
	Handling time + Tagging time + Month + Family	70.67	4.67	7.3	4	0.1	
	Tagging time + Surgery count + Month + Family	72.31	6.31	5.84	4	0.2	
	Handling time + Tagging time + Surgery count + Month + Family	72.91	6.91	8.34	5	0.1	
	Depth + Tagging time + Surgery count + Month + Family	74.85	8.85	5.86	5	0.3	
	Depth + Tagging time + Surgery count + Month + Fish size + Family	77.79	11.79	5.9	6	0.4	
	6	Handling time + Family	77.51	0.00	8.28	2	0.02
		Handling time	77.55	0.04	5.43	1	0.02
Handling time + Month+ Family		78.13	0.62	10.32	3	0.02	
Month		79.66	2.15	3.22	1	0.07	
Handling time + Tagging time + Month + Family		79.75	2.24	11.22	4	0.02	
Family + Month		79.85	2.34	5.43	2	0.07	
Tagging time + Month+ Family		80.73	3.22	6.96	3	0.07	
Null		81.06	3.55				
Tagging time + Fish size + Month+ Family		81.61	4.10	9.98	4	0.06	
Handling time + Tagging time + Surgery count + Month + Family		82.28	4.77	11.73	5	0.04	
Tagging time + Surgery count + Month + Family		84.22	6.71	9.33	5	0.1	
Depth + Tagging time + Surgery count + Month + Family		87.07	9.56	9.36	6	0.2	

Table 6. Cox proportional hazards models results for best fitting models (lowest AICc) of boat-tagged fish at both 4 and 6 days after tagging. All models include probability of presence as the dependent variable and list independent variables included in each individual model. P-values are from the log-rank test.

Days after tagging	Covariates	Coefficient	SE	Hazard Ratio	95% CI	<i>p</i>
4	Handling time	-0.020	0.01	0.980	0.961-0.999	0.048*
6	Handling time	-0.022	0.009	0.978	0.960-0.996	0.016*
	Family: Lutjanidae	Reference	-	-	-	-
	Family: Serranidae	0.937	0.597	2.554	0.793-8.23	0.116

For *in situ* tagged fish, month was the only covariate included in the best fitting model at 4 days after tagging and both month and fish size were in the best fitting model at 6 days after tagging (Table 7). However, the global log-rank tests examining significance of the models overall were nonsignificant in both cases. The hazard ratio confidence intervals crossed one for all covariates in the best-fitting models, indicating no effect. Additionally, the particularly wide confidence interval for fish size in the best-fitting 6-day model indicated the point estimate was unreliable (Table 8). For all covariates in both best-fitting models, the proportional hazard assumption was supported by a nonsignificant relationship between scaled Schoenfeld residuals and time.

Table 7. Cox proportional hazards models examining fish survival for fish tagged *in situ* (n=70) at both 4 and 6 days after tagging. Models are ranked by AICc values. All models include probability of presence as the dependent variable and list independent variables included in each individual model. P-values are from the log-rank test.

Days after tagging	Hazards model	AICc	$\Delta$ AICc	$\chi^2$	df	p	
4	Month	40.38	0.00	3.26	1	0.07	
	Fish size + Month	41.49	1.11	4.51	2	0.1	
	Handling time	41.65	1.27	2.34	1	0.1	
	Depth + Month	41.99	1.61	3.96	2	0.1	
	Null	42.19	1.81				
	Handling time + Fish size	42.30	1.92	3.78	2	0.2	
	Handling time + Family	42.74	2.36	3.25	2	0.2	
	Fish size + Family + Month	43.24	2.86	5.05	3	0.2	
	Depth + Family + Month	43.76	3.38	4.46	3	0.2	
	Handling time + Fish size + Family	43.79	3.41	4.45	3	0.2	
	Handling time + Depth+ Family	44.77	4.39	3.41	3	0.3	
	Tagging time + Fish size + Family + Month	45.21	4.83	5.09	4	0.3	
	Handling time + Fish size + Surgery count + Family	45.57	5.19	4.52	4	0.3	
	Tagging time + Depth + Family + Month	45.92	5.54	4.49	4	0.3	
	Handling time + Depth+ Surgery count + Family	46.97	6.59	3.44	4	0.5	
	Tagging time + Fish size + Surgery count + Family + Month	47.53	7.15	5.11	5	0.4	
	6	Fish size + Month	57.43	0.00	5.69	2	0.06
		Fish size	57.84	0.41	3.17	1	0.08
Handling time + Fish size + Surgery count		57.87	0.44	5.41	3	0.1	
Fish size + Surgery count		58.37	0.94	4.45	2	0.1	
Month		58.70	1.27	2.03	1	0.2	
Null		58.86	1.43				
Fish size + Surgery count + Month		58.90	1.47	6.48	3	0.09	
Depth + Month		59.52	2.09	3.5	2	0.2	
Handling time + Fish size + Surgery count + Family		59.54	2.11	5.67	4	0.2	
Surgery count		60.17	2.74	1.15	1	0.3	
Depth + Surgery count		60.92	3.49	1.72	2	0.4	
Fish size + Surgery count + Family + Month		60.95	3.52	6.68	4	0.2	
Depth + Surgery count + Month		61.02	3.59	3.94	3	0.3	
Handling time + Depth+ Surgery count		62.10	4.67	2.32	3	0.5	
Tagging time +Depth + Surgery count + Month		62.88	5.45	4.62	4	0.3	
Tagging time + Fish size + Surgery count + Family + Month		63.19	5.76	7.5	5	0.2	
Handling time + Depth+ Surgery count + Family		64.08	6.65	2.64	4	0.6	
Tagging time +Depth + Surgery count + Family + Month		64.97	7.54	4.87	5	0.4	

Table 8. Cox proportional hazards models results for best-fitting models of *in situ* tagged fish. All models include probability of presence as the dependent variable and list

independent variables included in each individual model. P-values are from the log rank test.

Days after tagging	Covariates	Coefficient	SE	Hazard Ratio	95% CI	p-value
4	Month	0.596	0.361	1.816	0.894-3.688	0.099
6	Month	0.34	0.236	1.413	0.890-2.243	0.143
	Fish size: Small	1.443	0.837	4.235	0.821- 21.845	0.085

## Discussion

Using an historic dataset of 8 years of fish tagging by Florida Fish and Wildlife Conservation Commission scientists in the Florida Keys, we examined factors *a posteriori* that influence probability of presence of internally tagged fish. At 6 days after tagging, Kaplan-Meier survival curves demonstrated that fish tagged *in situ* had a 24% higher probability of detection within the acoustic array (i.e. 75% lower probability of disappearing) compared to fish tagged on the boat. Tagging method was the only factor affecting the risk of disappearance when we examined the initial Cox proportional hazards model assessing the probability of presence of all fish.

In this study, there were several variables that could not be included in the initial hazards model because of correlation, but their inclusion and limited influence in the subsequent boat tagged and *in situ* tagged models reinforced that the tagging method was the most important factor in risk of disappearance from the array. Acoustic tracking data of *in situ* surgically tagged fish from two other telemetry studies also demonstrate the benefit of tagging method, indicated by high survival rates (97%–100%) post-surgery (Tuohy et al. 2015, Bryan et al. 2019). The decrease in probability of presence of boat-tagged fish could be due to several factors. As described in Feeley et al. (2018) and Herbig et al. (2019), all fish tagged on the boat were returned to the seafloor via divers after they recovered from anesthesia to ensure a safe return to the reef. Nevertheless, the tagged fish may still have suffered from barotrauma, increased stress from being caught by hook and line, increased handling times (which could also increase the impacts of barotrauma), or long-lasting effects of anesthesia. All these factors could increase risk of boat-tagged fish disappearing from the array.

At the start of *in situ* tagging, we decided not to use anesthesia at depth because we discovered that fish held ventral side up with their eyes covered were just as calm as anesthetized fish. We also deemed it advantageous to avoid unnecessarily impairing the tagged fish's response to predators once the fish was released into sheltering habitat after surgery. Using anesthesia during fish surgeries may not always be the best course of action in every situation, and all potential effects on the fish must be considered (Damon-Randell et al. 2010; Lowerre-Barbieri et al. 2014). We believe the benefits of reduced total handling time for fish tagged *in situ* versus fish tagged on the boat, which usually included a recovery period (mean  $\pm$  SE: *In situ* = 9.30  $\pm$  0.31 min, Boat = 72.2  $\pm$  6.00 min), coupled with immediate release into protective habitat and the lack of pressure and temperature changes, explain the increased

probability of presence within the acoustic array for *in situ* tagged fish. The increased probability of presence of fish tagged *in situ* compared to fish tagged on the boat indicates that any negative effects due to the lack of anesthesia are minimal and do not outweigh the benefits of *in situ* tagging.

There were several surprising results presented from the analysis of this data. Some of the variables that were originally believed to impact the probability of detection were either not influential in the hazards models or had the opposite effect. For example, we hypothesized that additional handling time would increase the risk of a tagged fish having an event. The models, however, suggested an increase in 1 min of handling time slightly decreased the risk of disappearance for boat-tagged fish, though the confidence intervals neared or crossed 1 in all cases, indicating little to no effect. Handling time may not have been very influential in risk of disappearance, but it is still surprising that increased time may have reduced risk, especially as handling times for fish tagged on the boat were high compared to other tagging studies (Starr et al. 2007, Bohaboy et al. 2019) and minimizing handling of fish has been reported as one of the most important considerations in implantation surgeries (Rub et al. 2014). For *in situ* tagging, handling time was not included in best-fitting models, but that may be because there was little variance in the handling times of fish tagged *in situ*.

Fish size was not a significant factor in the best fitting models. Fish tagged in this study varied between 32–107 cm TL, a range large enough that differences in probability of presence because of size were expected. We hypothesized that smaller fish would be at a higher risk of disappearance because they might not have the same energy resources to aid in recovery as larger fish or they may be more susceptible to predation. However, this was not supported by the models. “Fish size” was included in the best fitting model for *in situ* tagged fish at 6 days after tagging but was not significant, and a large spread in the hazard ratio confidence interval (0.82-21.84) represented high uncertainty in the hazard ratio estimate. While there are likely species-specific differences (e.g, body type, stress tolerance) that influence probability of presence of different sized fish, in our study fish size did not significantly affect probability of presence post-tagging. Also, fish less than 20 cm FL have been shown to have high survival from internal tagging (Klinard et al. 2018), suggesting that surgery and implantation of appropriately sized tags for the body size of the fish may not impair survival, regardless of fish size.

Fish family was also not a significant covariate, although differences in tolerance to barotrauma and handling were seen among species. The high number of species in this study (which originally led to overparameterization in models) and the unevenness of species between tagging methods resulted in grouping species by family. There are physiological differences between species of the same family, and grouping them by family may have masked these differences and may help explain why family did not affect survivorship. Although an in-depth look at the effect of tagging method on species was not possible in this study, a planned, paired study with fewer species may find that fish species influences probability of presence. For any tagging project, factors such as body type, susceptibility to barotrauma, and stress tolerance should be considered when deciding on the appropriate tagging method.

Water temperatures and differences between water and air temperatures vary throughout the year and could affect the risk of a fish disappearing from the array, but month as a proxy for temperature did not have a significant influence in either boat-tagged or *in situ* tagged models. Life history traits of the fish families (e.g. the time of year that they reproduce) are also linked to time of year and water temperature, and thus linked to the variable month. Although time of year was not a significant in this study it should be considered when deciding how to maximize fish survival and probability of presence when setting up a tagging project.

Experience of the surgeon has been shown to influence tag retention and survivorship (Cooke et al. 2003; Deter et al 2010), but this was not seen in our study. Surgery count was not in any best-fitting model, but was a covariate in the third best-fitting model for both the initial model at 4 days after tagging and the *in situ* model at 6 days after tagging. Although the effect was not statistically significant, both models indicated an increase in surgery count decreased risk of fish disappearance. Consistent training among surgeons may have reduced the effect of surgery count enough so that other variables had larger influences. Before the start of a tagging project, surgeons practiced the tagging procedure with guidance from an experienced team member, and initial training was provided by a professional plastic surgeon (D. Hawtof, personal communication). Additionally, less experienced surgeons were always paired with an experienced surgeon during the tagging procedure to provide guidance during both boat and *in situ* tagging. The training and oversight throughout the tagging procedure may have helped to reduce the effect of surgeon experience on risk of disappearance.

Hazards models were analyzed at both 4 and 6 days after tagging because there was discrepancy in the literature about how long after surgery to examine survival related to the tagging procedure. Results between these two time periods were similar (e.g., hazard ratios for tagging method in the initial model differed by only 0.015), but we felt it was informative to present both cases. Although differences between the results at both time periods were minimal, they are still interesting to note because they show how the dynamics of fish survival may subtly shift over time. The maximum time after surgery that a fish was still detected was just over 4 years (data from this fish was analyzed in Feeley et al. 2018), and a possible future direction of work could include examining longer term differences in detection patterns between different tagging methods, particularly if the goal is to maximize data acquisition. Analyzing probability of presence on a longer time frame may find different factors which are more influential than those found in this study, but consideration should be given to whether disappearances from the array longer than 6 days post-surgery are a result of the tagging procedure or a natural event.

This study was not originally designed to rigorously examine all factors affecting boat- and *in situ* tagged fish. Therefore, some variables may not have proven as influential as they would in a more systematic study. Depth was expected to have more of an influence on hazard because detrimental effects of barotrauma have been shown to increase with depth of capture (Hannah and Matteson 2007). In this study, depth may not have been the best representation of the severity of barotrauma. Boat-tagged fish were generally caught using hook and line and were not necessarily caught from the seafloor, which was the depth recorded, and furthermore, mean depth of capture of boat-tagged fish was significantly

shallower compared to *in situ* tagged fish (Wilcoxon two-sample rank test,  $p < 0.05$ ). Fish that were near the surface or mid-water column when caught on hook and line would have a greater depth recorded than where they were physically caught in the water column, meaning that they may have exhibited fewer signs of barotrauma than if they had actually been caught at the depth recorded. Fish tagged *in situ* were caught via baited traps on the seafloor, so the depth of capture was the depth of the trap and the actual depth of the fish when it entered the trap. Additionally, after the start of *in situ* tagging, this method was preferentially chosen over tagging on the boat at deep sites and only a few fish were captured, tagged, and released from the boat in deep water (>30m) and *in situ* tagged fish had a higher overall sample size compared to boat-tagged fish. The method of tagging was based on what was deemed best for survival of the fish and logistically made sense for each tagging event. If boat tagging data had included more fish captured from deep water, resulting in no discrepancy in mean depth per tagging method, we hypothesize depth would have had a larger effect on survival. Additionally, comparing risk of disappearance between tagging methods where boat-tagged fish were either released at the surface or brought back down to depth for release (the method used for all boat-tagged fish in this study) would further explore the effects of depth, barotrauma, and release method.

Fight time, location of hook placement on fish, whether the fish exhibited signs of barotrauma, whether a fish with barotrauma was vented before its return to depth, and overall health of the fish at time of release were not often recorded and thus were not included as covariates in the hazards models. The amount a time a fish spent in a trap could influence the fish's health and probability of presence after tagging, but the time a trap was baited does not equal the time a fish was in a trap (a trap may have been baited and left for 12 hours, but a fish may have entered the trap at hour 11). Use of cameras for identifying how long fish were in traps and recording specifics on condition upon release would provide more details on why risk of disappearance was higher in boat-tagged fish.

This study demonstrated some of the limitations of *a posteriori*-designed study including correlated variables and missing data (particularly during the initial stages of conducting acoustic telemetry research when it was not known what supplementary data would be beneficial to record). However, despite these caveats, we believe that this historic dataset using over 100 internally tagged fish representing 14 different species surgically tagged by 11 different scientists was robust enough to demonstrate that tagging method had an effect on risk of fish disappearance. Telemetry studies are expensive to conduct, both in terms of effort and money, and often outcomes are not known until months later when the data can be downloaded. Therefore, it is critical to have a better understanding of how tagging method influences probability of presence (which can be considered a proxy for fish survivorship). By examining the effects of tagging methods, we can inform future telemetry studies, thereby increasing the usefulness of telemetry data.

This study has shown that there were clear benefits to tagging fish *in situ*, though due to high correlation among variables we are unable to pinpoint the source behind decreased risk of disappearance compared to boat-tagged fish. The lack of barotrauma, shorter handling time, lack of anesthesia, and use of baited traps instead of hook and line may all have played a role in increasing an *in situ* tagged fish's probability

of presence. We understand that this *in situ* method may not always be practical. *In situ* tagging can increase the amount of effort spent to tag each fish because of the logistics required and the time limitations when tagging at deeper depths. Some target species may be located outside recreational diving limits, which can increase effort and cost for specialized training and dive gear. Also, in this study we used baited traps to capture fish *in situ*, but other methods should be considered if the species of interest is unlikely to be captured in this manner. Furthermore, studies that rely on anglers to supply the tagging subjects or focus on species found in very shallow water may not find *in situ* tagging feasible or worthwhile. However, we suggest that all aspects of the tagging procedure, from tagging method (e.g. on a boat vs. *in situ*) to use of anesthesia, method of capture, and method of release be carefully considered for each target species to reduce stress to the fish, and maximize success of the study.

## Conclusions

In this study, fish internally tagged *in situ* with acoustic tags were ~75% less likely to disappear from the receiver array (i.e. mortality, emigration, or tag loss event) shortly after tagging compared to fish brought to the surface and tagged on a boat. Other factors had little to no influence on probability of presence after tagging, but correlation of variables limited what could be included in hazards models. Despite the limitations due to correlation, fish had a higher probability of being present and a lower probability of disappearance when tagged with the *in situ* methods presented. Therefore, when designing a telemetry study, serious consideration of tagging method (*in situ* versus on a boat) and other variables (capture method, release method, use of anesthesia, etc.) should be evaluated because they play a critical role in the overall health of fish and success of the study. Implanting internal acoustic tags *in situ* is not a practical method for every species of interest and for every environment, but given the increased probability of presence demonstrated here, we suggest it be considered for fish species where applicable.

## Declarations

### Ethics approval and consent to participate

Acoustic tagging procedures in this study were approved by Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute and every effort was made to follow accepted standards and ensure the ethical treatment of captured fish. This research was conducted under scientific research permits issued by the Florida Keys National Marine Sanctuary (FKNMS-2008-015, FKNMS-2013-040, FKNMS-2013-040-A2, FKNMS-2018-047) and the Dry Tortugas National Park (DRT0-2008-SCI0003, DRT0-2010-SCI-0006).

### Consent for publication

Not applicable.

### Availability of data and materials

The datasets generated during and/or analyzed during the current study are available by request in the FWCDL repository [<https://f50006a.eos-intl.net/F50006A/OPAC/Details/Record.aspx?BibCode=5386179>].

## Competing interests

The authors declare that they have no competing interests.

## Funding

Research was supported by National Park Service CESU contract H5000065040-J5281060165, USGS State Partnership Program grant 08ERAG00070, NOAA NMFS Coral Reef Conservation Program grants NA17RJ1226 and NA08OAR4320892, and NOS Agreement # MOA-21010-026/8081.

## Author's contributions

JK analyzed the data. JK, DM, JH, MF, and AA contributed to the interpretation of results JK, DM, JH, AA, MF, and PB contributed to the writing of the manuscript. PB, MF, DM, JK, AA, and JH performed fieldwork. AA, DM, and MF secured funding. All authors read and approved the manuscript.

## Acknowledgements

We thank B Binder, A Collins, M Dancy, D DeMaria, D Eaken, D Hawtof, J Javech, A Johnson, M McCallister, J Renchen, A Tobin, and S Walters-Burnsed for assistance in the field. We also thank S Barbieri for sharing data and Dry Tortugas National Park Staff and the crews of the M/V Fort Jefferson, M/V Spree, M/V Peter Gladding, and NOAA ship Nancy Foster for helping with logistics. Thanks to E Ault, K Parsons, C Shea, and two anonymous reviewers for valuable manuscript comments and D Fields and C Ames for assistance with bathymetry data. In memoriam Jeff Simonds, FWC staff (April 24<sup>th</sup> 1978–February 18<sup>th</sup>, 2010), and David Hawtof, FWC volunteer (September 5<sup>th</sup>, 1933–February 5<sup>th</sup>, 2019), who contributed to this study.

## References

Atkins JL, Morris JA, Green SJ. *In situ* tagging technique for fishes provides insight into growth and movement of invasive lionfish. *Ecol Evol.* 2014;4(19):3768-3777.

Balázs G, Lewarne B, Herczeg G. *In situ* underwater tagging of aquatic organisms: a test using the cave-dwelling olm, *Proteus anguinus*. *Ann Zool Fennici.* 2015;52(3):160-166. [doi.org/10.5735/086.052.0303](https://doi.org/10.5735/086.052.0303)

Bohaboy EC, Guttridge TL, Hammerschlag N, Van Zinnicq Bergmann MP, Patterson III WF. Application of three-dimensional acoustic telemetry to assess the effects of rapid recompression on reef fish discard mortality. *ICES J Mar Sci.* 2019;77(1):83-96.

- Bryan DR, Feeley MW, Nemeth RS, Pollock C, Ault JS. Home range and spawning migration patterns of queen triggerfish *Balistes vetula* in St. Croix, US Virgin Islands. *Mar Ecol Prog*. 2019;616:123-139. [doi.org/10.3354/meps12944](https://doi.org/10.3354/meps12944)
- Cooke SJ, Graeb BDS, Suski CD, Ostrand KG. Effects of suture material on incision healing, growth and survival of juvenile largemouth bass implanted with miniature radio transmitters: case study of a novice and experienced fish surgeon. *J Fish Biol*. 2003;62:1366–1380.
- Crossin GT, Heupel MR, Holbrook CM, Hussey NE, Lowerre-Barbieri SK, Nguyen VM, Raby GD, Cooke SJ. Acoustic telemetry and fisheries management. *Ecol Appl*. 2017;27(4):1031-49.
- Curtis JM, Johnson MW, Diamond SL, Stunz GW. Quantifying delayed mortality from barotrauma impairment in discarded red snapper using acoustic telemetry. *Marine and Coastal Fisheries*. 2015;7:434-49.
- Damon-Randall K, Bohl R, Bolden S, et al. Atlantic sturgeon research techniques. NOAA technical memorandum NMFSNE-215. Woods Hole, Mass: National Marine Fisheries Service Northeast. 2010;19.
- Dance MA, Moulton DL, Furey NB, Rooker JR. Does transmitter placement or species affect detection efficiency of tagged animals in biotelemetry research? *Fish Res*. 2016;183:80–85.
- Eberts RL, Somers CM. Venting and descending provide equivocal benefits for catch-and-release survival: Study design influences effectiveness more than barotrauma relief method. *N Am J Fish Manag*. 2017;37:612-623. [doi.org/10.1080/02755947.2017.1307292](https://doi.org/10.1080/02755947.2017.1307292)
- Feeley MW, Morley D, Acosta A, Barbera P, Hunt J, Switzer T, Burton M. Spawning migration movements of Mutton Snapper in Tortugas, Florida: Spatial dynamics within a marine reserve network. *Fish Res*. 2018;204:209-223.
- Gallagher AJ, Serafy JE, Cooke SJ, Hammerschlag N. Physiological stress response, reflex impairment, and survival of five sympatric shark species following experimental capture and release. *Mar Ecol Prog Ser*. 2014;496:207-218.
- Hannah RW, Matteson KM. Behavior of nine species of Pacific rockfish after hook-and-line capture, recompression, and release. *Trans Am Fish Soc*. 2007;136:24-33.
- Herbig JL, Keller JA, Morley D, Walter K, Barbera P, Acosta A. Examining movement patterns of yellowtail snapper, *Ocyurus chrysurus*, in the Dry Tortugas, Florida. *Bull Mar Sci*. 2019;95(1):45-67.
- Hussey NE, Kessel ST, Aarestrup K, Cooke SJ, Cowley PD, Fisk AT, et al. Aquatic animal telemetry: a panoramic window into the underwater world. *Science*. 2015;348(6240):1255642.
- Jepsen N, Thorstad EB, Havn T, Lucas MC. The use of external electronic tags on fish: an evaluation of tag retention and tagging effects. *Anim Biotelemetry*. 2015;3:49.

- Keller JA, Herbig JL, Morley D, Wile A, Barbera P, Acosta A. Grouper tales: Use of acoustic telemetry to evaluate grouper movements at Western Dry Rocks in the Florida Keys. *Mar Coast Fish*. 2020;12:290-307.
- Kessel ST, Hussey NE. Tonic immobility as an anaesthetic for elasmobranchs during surgical implantation procedures. *Can J Fish Aquat Sci*. 2015; 72(9):1287-91.
- Kleinbaum DG, Klein M. *Survival analysis*. New York: Springer; 2012. p. 3.
- Klinard NV, Halfyard EA, Fisk AT, Stewart TJ, Johnson TB. Effects of surgically implanted acoustic tags on body condition, growth, and survival in a small, laterally compressed forage fish. *Trans Am Fish Soc*. 2018;147:749-757.
- Lindholm J, Fangman S, Kaufman L, Miller S. *In situ* tagging and tracking of coral reef fishes from the Aquarius Undersea Laboratory. *Mar Technol Soc J*. 2005;39:68-73.
- Lowerre-Barbieri SK, Villegas-Ríos D, Walters-Burnsed S, Bickford J, Cooper W, Muller R, Trotter A. Spawning site selection and contingent behavior in Common Snook, *Centropomus undecimal*. *PloS one* 2014; 9(7).
- Lowerre-Barbieri S, Burnsed S, Bickford J, Boucek R, Staley H. Report on the Integrated Tracking of Aquatic Animals in the Gulf of Mexico (iTAG) 2017 workshop: building network capacity. 2017. Florida Fish and Wildlife Conservation Commission, St. Petersburg.
- Lucas MC, Baras E. Methods for studying spatial behavior of freshwater fishes in the natural environment. *Fish and Fisheries*. 2000;1:283-316.
- McCallister M, Renchen J, Binder B, Acosta A. Diel activity patterns and movement of invasive lionfish (*Pterois volitans/P. miles*) in the Florida Keys identified using acoustic telemetry. *Gulf Caribb Res*. 2018;29(1):27-40.
- Piraino MN, Szedlmayer ST. Fine-scale movements and home ranges of Red Snapper around artificial reefs in the Northern Gulf of Mexico. *Trans Am Fish Soc*. 2014;143(4):988-998.
- R Core Team. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. 2019; URL <https://www.R-project.org/>.
- Rub AMW, Jepson N, Liedtke TL, Moser ML, Weber EPS III. Surgical insertion of transmitters and telemetry methods in fisheries research. *Am J Vet Res*. 2014;75(4):402-416.
- Rudershausen PJ, Buckel JA, Hightower JE. Estimating reef fish discard mortality using surface and bottom tagging: effects of hook injury and barotrauma. *Can J Fish Aquat Sci*. 2014;71: 514–520 [dx.doi.org/10.1139/cjfas-2013-0337](https://doi.org/10.1139/cjfas-2013-0337)

- Rummer JL, Bennett WA. Physiological effects of swim bladder overexpansion and catastrophic decompression on Red Snapper. *Trans Am Fish Soc.* 2005;134:1457–1470.
- Runde BJ, Rudershausen PJ, Sauls B, Mikles CS, Buckel JA. Low discard survival of gray triggerfish in the southeastern US hook-and-line fishery. *Fish Res.* 2019;219:105313
- Sigurdsson T, Thorsteinsson V, Gústafsson L. *In situ* tagging of deep-sea redfish: application of an underwater, fish-tagging system. *ICES J Mar Sci.* 2006;63:523-531.
- Simpfendorfer CA, Huveneers C, Steckenreuter A, Tattersall K, Hoenner X, Harcourt R, Heupel, MR. Ghosts in the data: false detections in VEMCO pulse position modulation acoustic telemetry monitoring equipment. *Anim Biotelemetry.* 2015;3(1):55.
- Skomal GB. Evaluating the physiological and physical consequences of capture on post-release survivorship in large pelagic fishes. *Fish Manag Ecol.* 2007;14:81-89.
- Sloan KA, Bouyoucos IA, Brooks EJ, Sneddon LU. Ethical considerations in fish research. *J Fish Biol.* 2019;94:556-577.
- Starr RM, Heine JN, Johnson KA. Techniques for tagging and tracking deepwater rockfishes. *N Am J Fish Manag.* 2000;20:597-609.
- Starr RM, Sala E, Ballesteros E, Zabala M. Spatial dynamics of the Nassau grouper *Epinephelus striatus* in a Caribbean atoll. *Mar Ecol Prog Ser.* 2007;343:239-249.
- Taylor C, Field D, Vander Pluym J, Viehman S, Ebert E. NCCOS Mapping: Seafloor Mapping Products for the Florida Keys National Marine Sanctuary from 2004-01-01 to 2016-12-31 (NCEI Accession 0170215). NOAA National Centers for Environmental Information. Dataset. 2018. <https://doi.org/10.7289/v55b00rz>. Accessed 11/22/2020.
- Topping DT, Szedlmayer ST. Site fidelity, residence time and movements of red snapper *Lutjanus campechanus* estimated with long-term acoustic monitoring. *Mar Ecol Prog Ser.* 2011;437:183-200.
- Tuohy E, Nemeth MI, Bejarano I, Schärer MT, Appeldoorn RS. *In situ* tagging of Nassau Grouper *Epinephelus striatus* using closed-circuit rebreathers at a spawning aggregation in Puerto Rico. *Mar Technol Soc J.* 2015;49:115-123.
- Venables WN, Ripley BD. Modern applied statistics with S-Plus. 4<sup>th</sup> ed. New York: Springer; 2002.
- Wagner GN, Cooke S., Brown RS, Deters KA. Surgical implantation techniques for electronic tags in fish. *Rev Fish Biol Fisher.* 2011;21:71-81.
- Williams LJ, Herbig JL, Szedlmayer ST. A cage release method to improve fish tagging studies. *Fish Res.* 2015;172:125-129.

Wilson S M, Raby G D, Burnett N J, Hinch S G, Cooke SJ (2014). Looking beyond the mortality of bycatch: sublethal effects of incidental capture on marine animals. *Biolog Conserv.* 2014;171:61-72.

## Figures

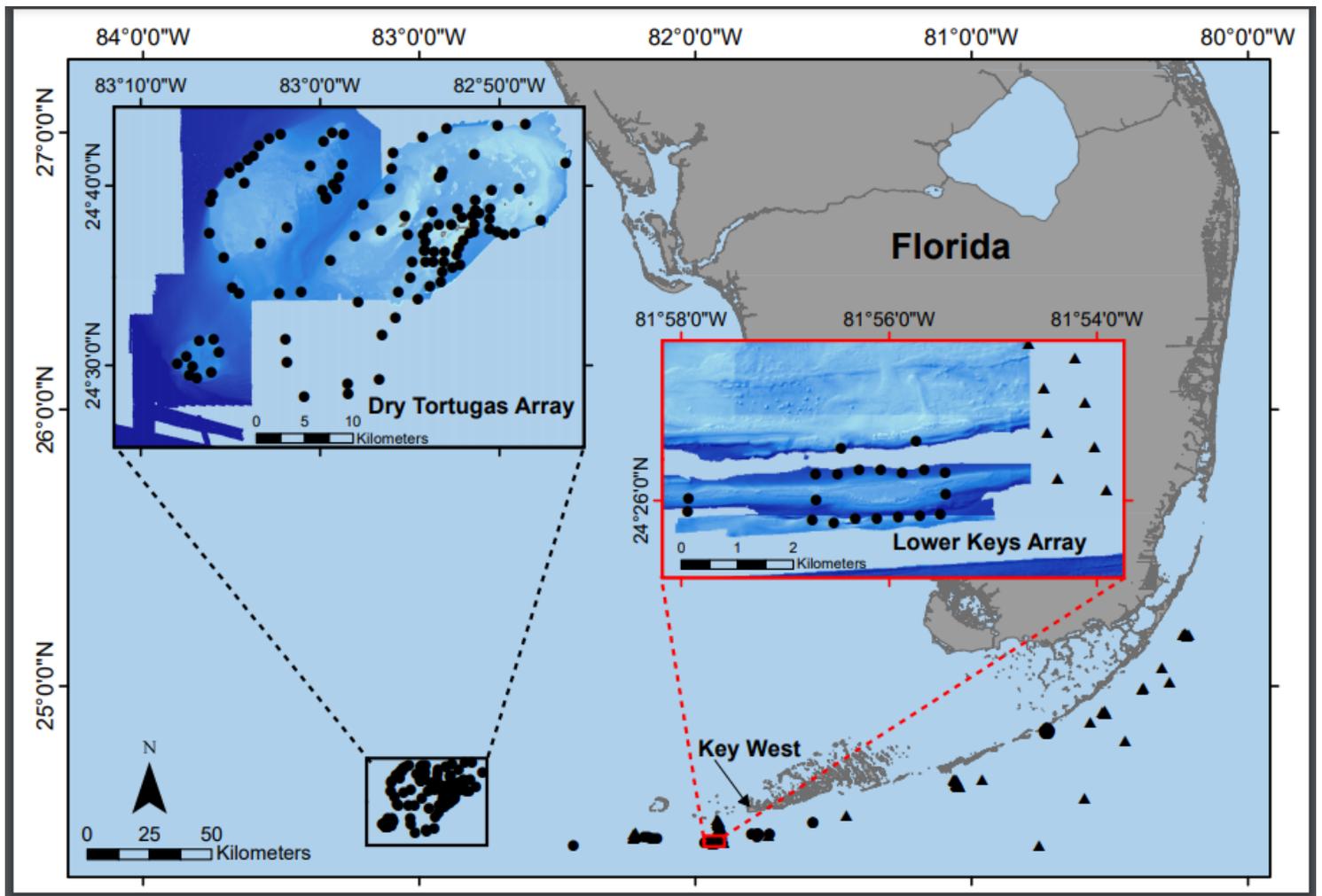
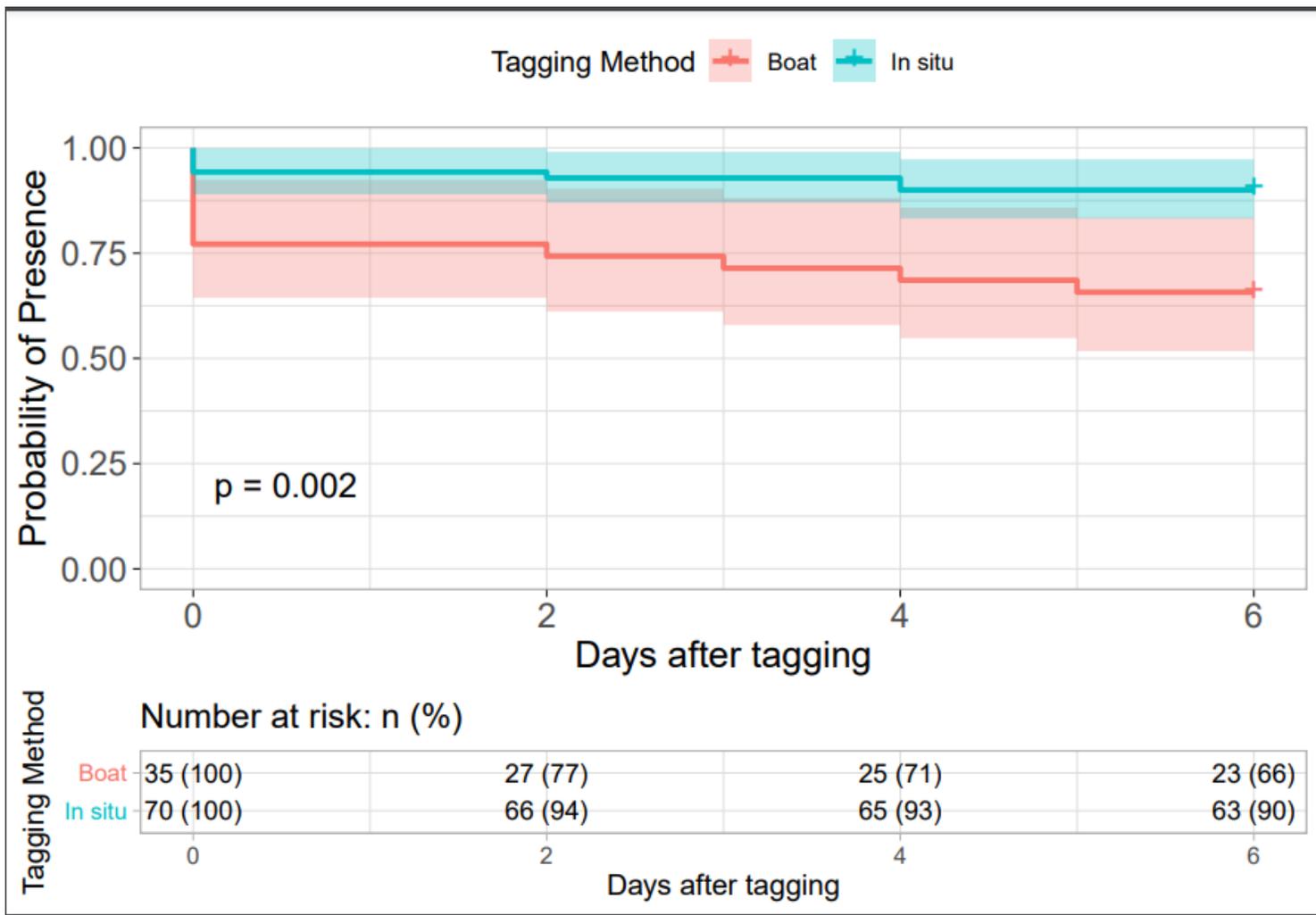


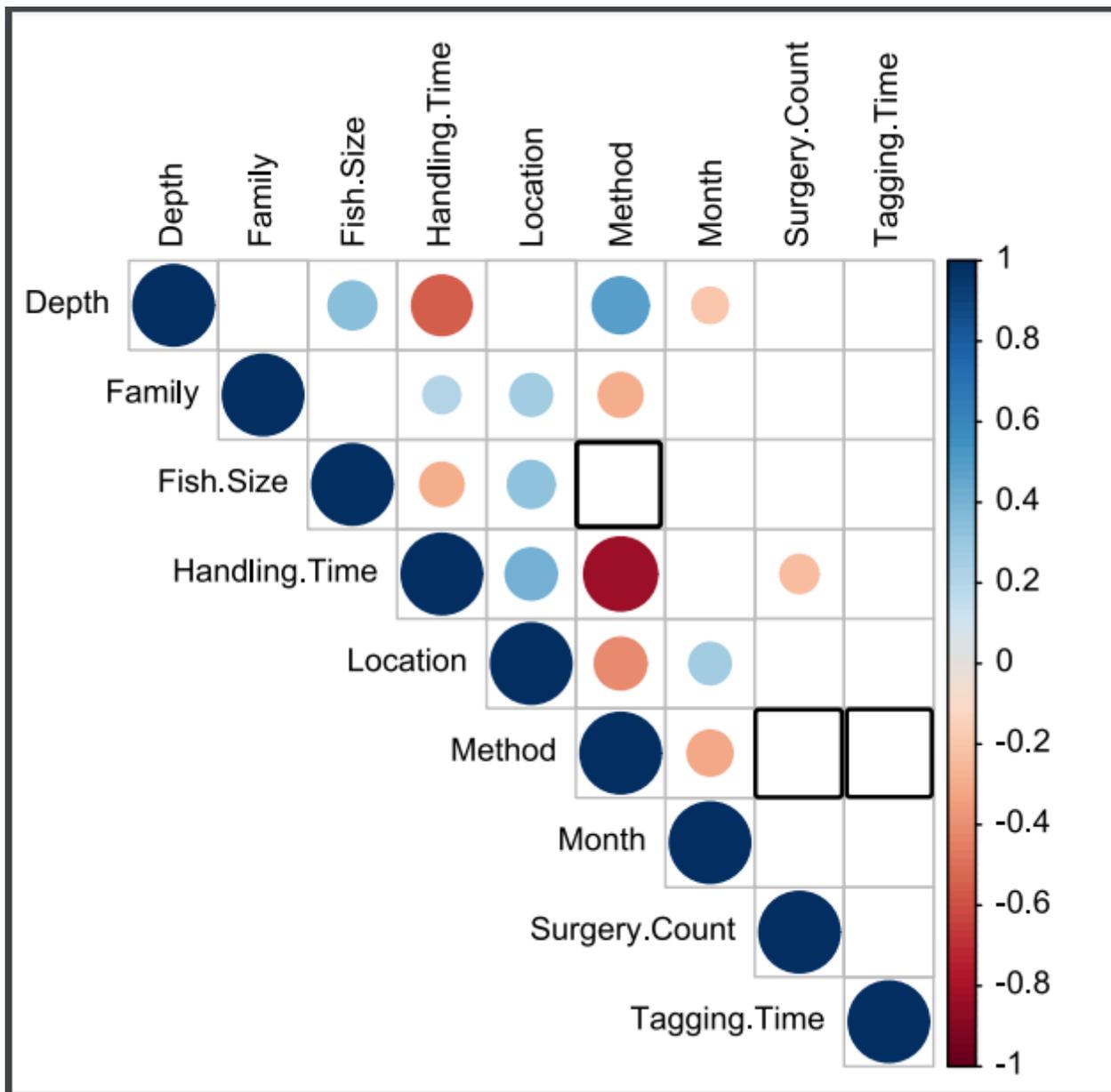
Figure 1

Fish tagging locations and acoustic receiver arrays in the Lower Florida Keys and Dry Tortugas. Fish and Wildlife Research Institute receivers are represented as circles and Integrated Tracking of Aquatic Animals in the Gulf of Mexico receivers are represented as triangles. Bathymetry data in the subplots shows depth as a gradient from light (shallower) to dark (deeper) blue (0 – 132 m). Receiver location depths ranged from 3 – 43 m. Receivers depicted on this map were deployed during different times from 2008 – 2018, depending on the study. Details regarding receiver timing can be found in Feeley et al 2018, Herbig et al 2019, and Keller et al 2020. Bathymetry data is a part of the Florida Keys National Marine Sanctuary Digital Atlas (Taylor et al. 2018).



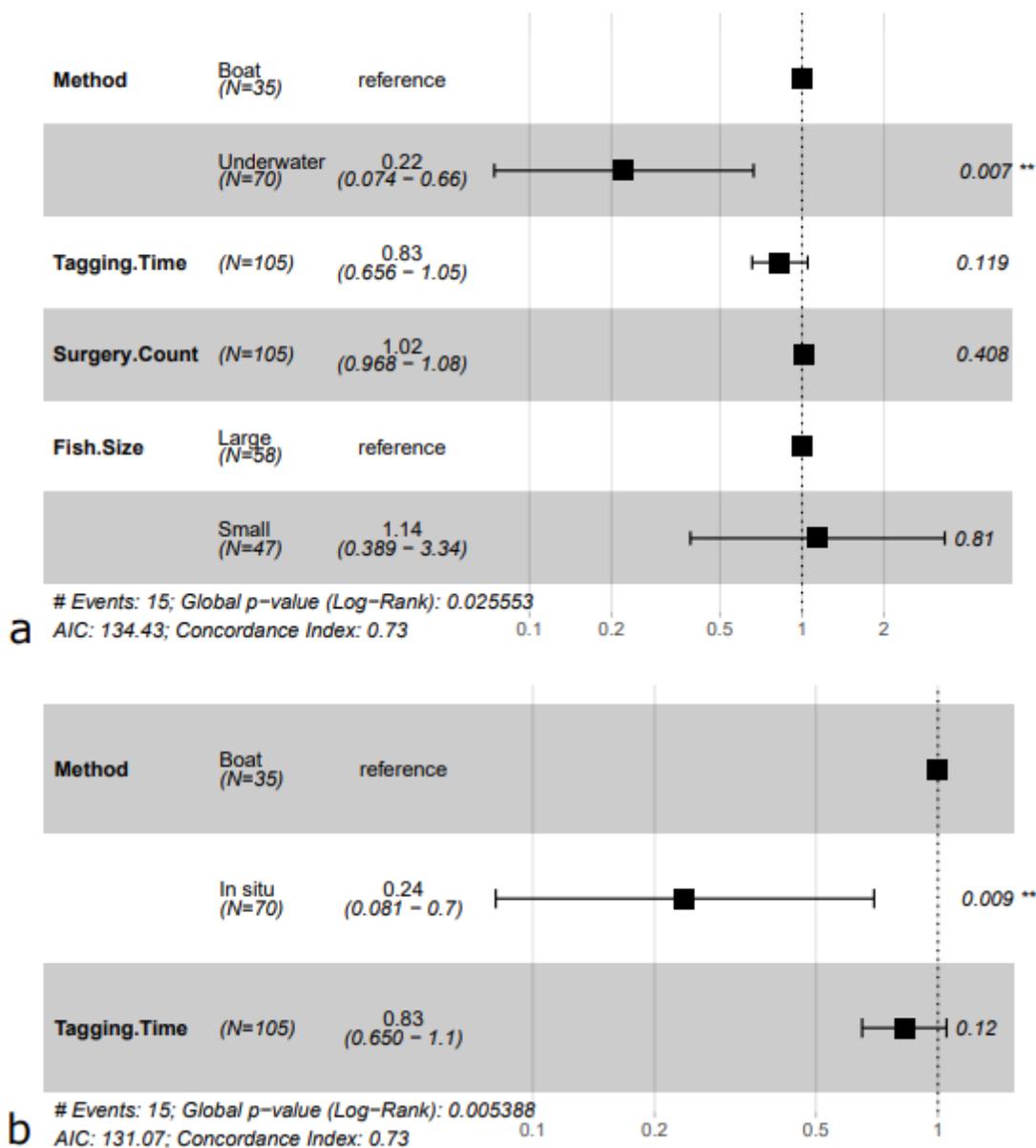
**Figure 2**

Kaplan–Meier survival curves showing probability of presence for fish tagged in situ and on the boat from day of tagging to 6 days afterward. Shaded areas indicate 95% confidence interval for the survival curves. A risk table shows the number of individual fish and percentage of total fish still detected in 2-day bins for both tagging methods.



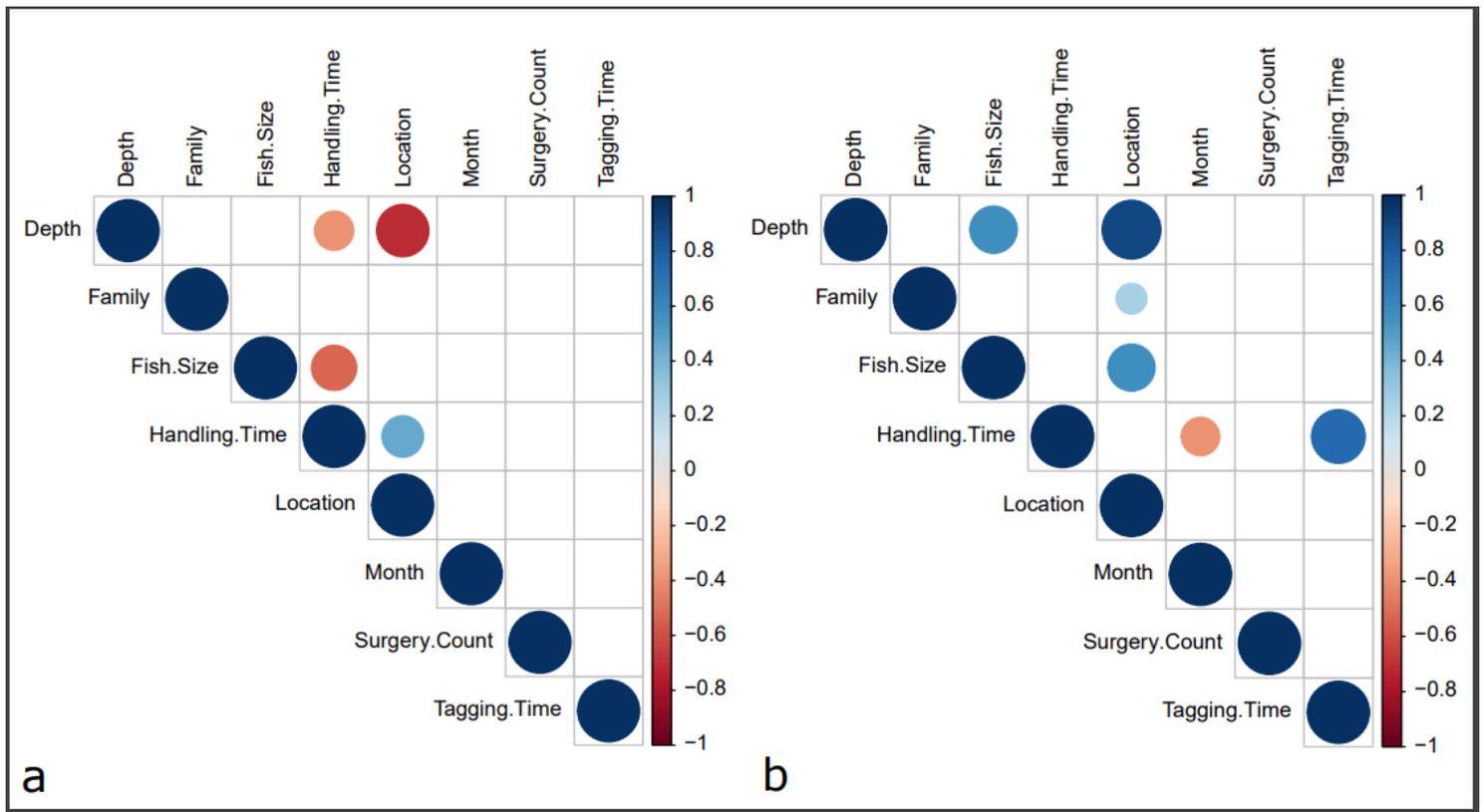
**Figure 3**

Pearson correlation coefficients for all covariates for all fish tagged. Size and color of dots indicate strength and direction of correlation. Boxes without dots indicate no statistically significant correlation ( $p > 0.05$ ). Boxes with a thick black outline indicate the variables included in the full model.



**Figure 4**

Forest plots showing covariate hazard ratios at 4 days after tagging for the a) full model and b) best-fitting Cox proportional hazard model. Hazard ratios and 95% confidence intervals for each covariate are shown with p-values listed on the right-hand side of the plots with asterisks indicating significance. Hazard ratio values less than 1 (represented by the dotted line) indicate a reduction in risk of disappearance from the array while values greater than 1 indicate increased risk of disappearance. Covariates with hazard ratios close to 1 have a marginal effect on hazard and confidence intervals crossing 1 indicate no significant effect.



**Figure 5**

Pearson correlation coefficients for all covariates for a) boat-tagged and b) in situ tagged fish. Size and color of dots indicate strength and direction of correlation. Boxes without dots indicate no statistically significant correlation ( $p > 0.05$ ).