Under Pressure: Comparing Fish Survivorship Between in Situ and Boat Tagging Methods Using Internal Acoustic Tags

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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 be used to answer more localized questions, such as patterns of habitat use in a specific location (Herbig et al. 2019, Keller et al. in press). 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). Mortality during the process of internally tagging a fish on a boat may be due to stress from barotrauma, changes in water and air temperature, prolonged fish handling, or the amount of time the fish spends on 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) 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) 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 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 completely 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; Rundershansen 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 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. (in press) 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 survivorship between boat and *in situ* tagging methods when using internal acoustic tags. 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 fish survivorship and 2) the effects of other tagging variables (e.g., handling time and surgeon experience) that might also play a role.

**Methods**

**Fish tagging**

Fourteen species of groupers (Serranidae) and snappers (Lutjanidae) were internally tagged with acoustic transmitters from 2008–2016 by Florida Fish and Wildlife Conservation Commission staff in the Florida Keys and Dry Tortugas (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. Fish caught in underwater traps 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. (in press). 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. 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. Fish that did not have complete tagging procedure data were excluded from analyses.

**Data validation**

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). Additionally, 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.

### Tagging variables

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. “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. The family name of fish (n=2), either Serranidae or Lutjanidae, was also included as a covariate to examine differences in survival based on physiological differences between taxonomic groups but to avoid overparametizing the models because of the high number of species (n=14).

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 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.

To determine if the tagging experience of the surgeon had an influence on survivorship, a variable called “surgeon experience” was created. The name of the surgeon and date and time of the surgery were used to assign each fish a surgery value based on how many surgeries the surgeon had previously completed. For example, surgery 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 17th fish a surgeon had tagged. If that value was less than the mean number of surgeries completed (among all surgeons), the surgeon experience was assigned as “low.” Alternatively, if the value was higher than the mean number of surgeries completed, the surgeon experience was assigned as “high.”

### Survival analysis

We examined survivorship of tagged fish using a Cox proportional hazards model, which 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). 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 significantly correlated with each other (p<0.05) were not included in the same hazards model.

The influence of tagging procedure variables on survivorship were 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. Due to discrepancy in time after
tagging to analysis of survival from the tagging procedure, we decided to determine survival at both 4
and 6 days after tagging. For each fish, the last day of its detection was used to calculate the number of
days it survived before an event. For example, if a fish was last detected 5 days after the tagging
procedure, it was marked as having an event at day 5. The term “survival” is used to refer to the fish being
present and detected by a receiver while an “event” could be mortality via predation or fishing pressure,
tag loss, or emigration. If a fish was detected past the 4- or 6-day mark, the number of days it survived
was truncated to 4 or 6 days, depending on which time frame was used for analysis.

To visually compare the survival probability and number of events 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 survival probability, 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 fish survival, two secondary hazards models were performed to assess which variables
influenced survival 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 survival. Hazard
ratios above a value of 1 indicate an increase in risk of an event 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 an event as the value of the covariate
increases by 1 unit. A hazard ratio greater than 1 is the proportional increase in risk of an event 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 an event (and thus probability of survival) while a hazard ratio at 1, or a confidence interval that
crosses 1, has no effect on the risk of an event (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 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 were excluded and two fish were excluded from analyses because they had only a single detection. No tagged fish detected at only one location had continuous, consistent detection patterns suspected of resulting from a discarded tag. Additionally, receivers in both arrays were often spaced farther apart to try to maximize coverage area. Most fish detected at a single location were groupers or small snappers that were not expected to make long-distance movements, and smaller movements could have been missed because of spacing between receivers. In total, 105 fish from 14 different species were included in analyses (35 boat tagged and 70 in situ tagged; Table 1).

The average total length was 57.0 ± 1.4 cm (mean ± SE) for Lutjanidae and 64.6 ± 1.7 cm for Serranidae. These values were used to determine whether the variable of “fish size” was “small” or “large” The average number of surgeries completed per surgeon was 9.55 ± 2.92, and this value was used for the determination of whether the variable “surgeon experience” was “low” or “high.” Mean handling time and depth varied between tagging method, but mean tagging time was similar (Table 2).

In situ tagged fish had a higher probability of survival (and remaining in the area) and lower chance of experiencing an event compared to fish tagged on the boat, based on Kaplan–Meier survival curves (Fig. 2). Six days after tagging, the survival probability of fish tagged on the boat was only 66% while survival of fish tagged in situ was 90%. The null hypothesis that there was no difference between the two methods in the probability of an event (mortality, tag loss, or emigration) from day of tagging to 6 days after tagging was rejected by a log-rank test (p = 0.002).

Figure 2 Kaplan–Meier survival curves showing survival probability 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 survival analysis by species and tagging method.

| Tagging method and fish species | Number of fish |
|---------------------------------|----------------|
| Boat tagged                      | 35             |
| Black grouper, *Mycteroperca bonaci* | 8              |
| Gray snapper, *Lutjanus griseus*  | 1              |
| Mutton snapper, *Lutjanus analis* | 14             |
| Red grouper, *Epinephelus morio*  | 1              |
| Yellowfin grouper, *Mycteroperca venenosa* | 1  |
| Yellowtail snapper, *Ocyurus chrysurus* | 10            |
| In situ tagged                   | 70             |
| Black grouper, *Mycteroperca bonaci* | 17             |
| Dog snapper, *Lutjanus jocu*     | 6              |
| Gag, *Mycteroperca microlepis*   | 2              |
| Gray snapper, *Lutjanus griseus* | 8              |
| Mutton snapper, *Lutjanus analis* | 13             |
| Nassau grouper, *Epinephelus striatus* | 8              |
| Red Hind, *Epinephelus guttatus* | 1              |
| Rock Hind, *Epinephelus adscensionis* | 1            |
| Scamp, *Mycteroperca phenax*     | 4              |
| Schoolmaster, *Lutjanus apodus*  | 1              |
| Yellowfin grouper, *Mycteroperca venenosa* | 8  |
| Yellowmouth grouper, *Mycteroperca interstitialis* | 1   |
| **Total**                        | **105**        |

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

|                  | Handling time (min) | Tagging time (min) | Depth (m)   |
|------------------|---------------------|--------------------|-------------|
| Boat-tagged      | 72.17 ± 6.02        | 6.37 ± 0.35        | 13.29 ± 2.14 |
| In situ tagged   | 9.30 ± 0.31         | 6.96 ± 0.27        | 24.61 ± 0.94 |
Fish size and tagging time 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).

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 significant correlation ($p > 0.05$).

### Table 3

| Days after tagging | Hazards model                      | AICc | ΔAICc | $\chi^2$ | df | $p$ |
|-------------------|------------------------------------|------|-------|---------|----|-----|
| 4                 | Method + Tagging time               | 131.2| 0.0   | 11.11   | 2  | 0.004|
|                   | Method                             | 131.5| 0.3   | 8.98    | 1  | 0.003|
|                   | Method + Tagging time + Fish size   | 133.3| 2.1   | 11.12   | 3  | 0.010|
|                   | Null                               | 137.5| 6.3   |         |    |      |
| 6                 | Method                             | 166.7| 0.0   | 9.78    | 1  | 0.002|
|                   | Method + Tagging time               | 167.6| 0.9   | 10.82   | 2  | 0.004|
|                   | Method + Tagging time + Fish size   | 169.7| 3     | 10.85   | 3  | 0.010|
|                   | Null                               | 173.4| 6.7   |         |    |      |

Hazards model results for the best fitting models indicate that fish internally tagged *in situ* were 76% less likely to have an event (one minus the hazard ratio) 4 days after tagging and 75% less likely to have an event 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 survival 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        | p     |
|-------------------|---------------------------------|-------------|-----|--------------|---------------|-------|
| 4                 | Tagging method: Boat            | Reference   | -   | -            | -             | -     |
|                   | Tagging method: *in situ*       | -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: *in situ*       | -1.378      | 0.476 | 0.252 | 0.099–0.641 | 0.004*|

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 an event while values greater than 1 indicate increased risk of an event. 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. Fish size and surgeon experience (thought to secondarily influence survival) were also correlated with each other. As a result of these correlations, three full models were created for fish tagged on the boat: 1) one with depth, surgeon experience, and all variables not correlated with each other, 2) one with depth, fish size, and all variables not correlated with each other, and 3) one with handling time, surgeon experience, and all variables not correlated with each other. Handling time was correlated with fish size, and thus the two could not be included in the same full model.

For *in situ* tagged fish, handling time and depth were not correlated with each other, but depth was correlated with fish size (Fig. 5b). Two 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.
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 significant correlation ($p > 0.05$).

Handling time was the only covariate 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 an event 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 survival 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 survival 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     | ΔAICc  | \(\chi^2\) | 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  | 0.10   |
|                   | Null                                               | 68.26    | 2.26   |             |    |        |
|                   | Handling time + Tagging time + Family              | 68.60    | 2.60   | 6.96        | 3  | 0.07   |
|                   | Tagging time + Family                              | 69.50    | 3.50   | 3.17        | 2  | 0.20   |
|                   | Tagging time + Fish size                           | 69.96    | 3.96   | 2.89        | 2  | 0.20   |
|                   | Handling time + Tagging time + Surgeon experience + Family | 70.87    | 4.87   | 7.47        | 4  | 0.10   |
|                   | Tagging time + Surgeon experience + Family         | 71.35    | 5.35   | 4.07        | 3  | 0.30   |
|                   | Tagging time + Fish size + Family                  | 71.41    | 5.41   | 3.89        | 3  | 0.30   |
|                   | Depth + Tagging time + Surgeon Experience + Family | 73.88    | 7.88   | 3.72        | 4  | 0.40   |
|                   | Depth + Tagging time + Fish size + Family          | 73.95    | 7.95   | 3.94        | 4  | 0.40   |
| 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 + Tagging time + Family              | 78.64    | 1.13   | 10.0        | 3  | 0.02*  |
|                   | Tagging time                                       | 80.11    | 2.60   | 3.21        | 1  | 0.07   |
|                   | Tagging time + Fish size                           | 80.50    | 2.99   | 5.32        | 2  | 0.07   |
|                   | Tagging time + Family                              | 80.74    | 3.23   | 4.69        | 2  | 0.10   |
|                   | Null                                               | 81.06    | 3.55   |             |    |        |
|                   | Tagging time + Fish size + Family                  | 81.13    | 3.62   | 7.40        | 3  | 0.06   |
|                   | Handling time + Tagging time + Surgeon experience + Family | 81.13    | 3.62   | 10.27       | 4  | 0.04   |
|                   | Tagging time + Surgeon experience + Family         | 82.87    | 5.36   | 5.30        | 3  | 0.20   |
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 survival 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  | ΔAICc | $\chi^2$ | df  | $p$  |
|--------------------|---------------------------------------------------|-------|-------|---------|-----|------|
|                    | Depth + Tagging time + Fish size + Family         | 83.42 | 5.91  | 7.77    | 4   | 0.10 |
|                    | Depth + Tagging time + Surgeon Experience + Family| 85.42 | 7.91  | 5.30    | 4   | 0.30 |

Table 6

For *in situ* tagged fish, handling time was the only covariate in the best fitting model at 4 days after tagging and fish size was the only covariate in the best-fitting model at 6 days after tagging (Table 7). However, the global log-rank test examining significance of the model overall was nonsignificant in both cases. Additionally, the confidence intervals for covariates in both models crossed 1, indicating no effect, and 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 survival 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  | ΔAICc | χ²   | df | p   |
|--------------------|----------------------------------------------------|-------|-------|------|----|-----|
| 4                  | Handling time                                      | 41.65 | 0.00  | 2.34 | 1  | 0.10|
|                    | Null                                               | 42.19 | 0.54  |      |    |     |
|                    | Handling time + Fish size                          | 42.30 | 0.65  | 3.78 | 2  | 0.20|
|                    | Handling time + Family                             | 42.74 | 1.09  | 3.25 | 2  | 0.20|
|                    | Handling time + Fish size + Family                 | 43.79 | 2.14  | 4.45 | 3  | 0.20|
|                    | Handling time + Surgeon experience + Family        | 44.65 | 3.00  | 3.4  | 3  | 0.30|
|                    | Handling time + Fish size + Surgeon experience + Family | 46.03 | 4.38  | 4.56 | 4  | 0.30|
|                    | Handling time + Depth + Surgeon experience + Family | 46.78 | 5.13  | 3.62 | 4  | 0.50|
| 6                  | Fish Size                                          | 57.84 | 0.00  | 3.17 | 1  | 0.08|
|                    | Handling time + Fish size                          | 58.62 | 0.78  | 4.45 | 2  | 0.10|
|                    | Null                                               | 58.86 | 1.02  |      |    |     |
|                    | Handling time + Fish size + Surgeon experience     | 59.94 | 2.10  | 4.74 | 3  | 0.20|
|                    | Depth                                              | 60.17 | 2.33  | 0.76 | 1  | 0.40|
|                    | Handling time + Depth                              | 61.43 | 3.59  | 1.61 | 2  | 0.40|
|                    | Handling time + Fish size + Surgeon experience + Family | 62.10 | 4.26  | 4.9  | 4  | 0.30|
|                    | Handling time + Depth + Family                     | 63.31 | 5.47  | 1.88 | 3  | 0.60|
|                    | Handling time + Depth + Surgeon experience + Family | 65.46 | 7.62  | 1.93 | 4  | 0.70|
Table 8
Cox proportional hazards models results for best-fitting models of *in situ* tagged sh. All models include survival 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                  | Handling time   | -0.316      | 0.214 | 0.729       | 0.479–1.109    | 0.14    |
| 6                  | Fish size:      |             |     |              |                |         |
|                    | Large           | Reference   | -   | -            | -              | -       |
|                    | Fish size:      | 1.378       | 0.837 | 3.965       | 0.769–20.44    | 0.01    |

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 survivorship of internally tagged fish. At 6 days after tagging, Kaplan-Meier survival curves demonstrated that fish tagged *in situ* had a 24% higher survival probability than fish tagged on the boat. Tagging method was the only factor affecting the risk of an event when we examined the initial Cox proportional hazards model assessing survival of all fish. Tagging *in situ* reduced the chance of fish having an event and thus increased the probability of survivorship by ~75% compared to tagging on the boat.

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 two subsequent models assessing hazards to the boat-tagged and *in situ* tagged fish independently reinforced that the tagging method was the most important factor for survivorship. Acoustic tracking data of *in situ* surgically tagged sh from two other studies also indicated high survival rates (97–100%) post-surgery (Tuohy et al. 2015, Bryan et al. 2019). The decrease in survival probability 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, or long-lasting effects of anesthesia. All these factors could increase risk of boat-tagged fish having an event. Unfortunately, it was not possible to know the exact fate of fish that had an event because this study did not include a VEMCO Positioning System (VPS) for triangulation of exact location or predation tags that change the transmitter ID code when a tag has entered the stomach of a predator.

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 and to be able to immediately release the fish 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 ± SE: *In situ* = 9.30 ± 0.31 min, Boat = 72.2 ± 6.00 min), coupled with immediate release into protective habitat and the lack of pressure and temperature changes, explain the increased survivorship for *in situ* tagged fish. The increased survival 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. Some of the variables that were originally believed to impact survivorship 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 hazard, 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 survival, but it is still surprising that increased time may have reduced risk, especially as minimizing handling of fish has been reported as one of the most important considerations in implantation surgeries (Rub et al. 2014). In the case of boat-tagged fish, where handling time had a marginal but significant effect, an increase in handling time could have resulted in better recovery from the anesthesia. For *in situ* tagging, handling time was not significant. Handling time was not included in the initial hazards model because of correlation with tagging method, but we believe that 1) the reduced handling time during *in situ* tagging contributed to the high survivorship and 2) decreased risk with increased handling time for boat tagged fish was due to the fish recovering from anesthesia.

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 survivorship because of size were expected. We hypothesized that smaller fish would be at a higher risk of an event 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 (0.77–20) represented high uncertainty in the hazard ratio estimate. While there are likely species-specific differences (e.g, body type, stress tolerance) that influence survival of different sized fish, in our study fish size did not significantly affect survival. 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 survival probability. 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.

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. In fact, surgeon experience was not a covariate in the top three parameterizations of any hazards model. Consistent training among surgeons may have reduced the effect of surgeon experience 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 survivorship.

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.

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 (> 30 m). 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 survivorship 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. All these factors could have affected the body condition and level of stress of the fish. Further testing of survival between fish tagged on the boat and fish tagged in situ would benefit from a planned, paired experiment to better determine how some of these other variables affect hazards to survival of internally tagged fish. This study also demonstrated some of the limitations of a posteriori-designed study. Unfortunately, additional tagged fish were excluded because of missing data, particularly during the initial stages of conducting acoustic telemetry research when it was not known what supplementary data would be beneficial to evaluate survivorship.

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 clearly had the largest effect on fish survival. 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 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 are clear benefits to tagging fish in situ. However, we understand that this method may not always be practical. In situ tagging can increase the amount of effort spent to tag each fish because an entire dive team is needed to tag one fish and there is limited time 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. 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. 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.

Conclusions

In this study, fish internally tagged in situ with acoustic coded tags were ~ 75% less likely to suffer an “event” (mortality, tag loss, or emigration) shortly after tagging compared to fish brought to the surface and tagged on a boat. Other factors had little to no influence on survival probability. Therefore, when designing a telemetry study, serious consideration should be given to the tagging method because it could 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 fish survivorship demonstrated here, we strongly suggest it be considered as the preferred tagging methodology for reef 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 (DRTO-2008-SCI0003, DRTO-2010-SCI0006).

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.

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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.

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Figures
Figure 1

Fish tagging locations in the Lower Florida Keys and Dry Tortugas
Figure 2

Kaplan–Meier survival curves showing survival probability 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.

\[ p = 0.002 \]
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 significant correlation (p >0.05).
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 an event while values greater than 1 indicate increased risk of an event. 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 significant correlation (p >0.05).