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MANAGEMENT BRIEF

A comparison of tag retention and mortality from two tagging methods for internal tag placement in Channel Catfish

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Abstract

Objective: Documenting the movement of Channel Catfish *Ictalurus punctatus* through telemetry, where a transmitter tag is surgically implanted in the fish, can provide valuable insight into the species' spatial ecology and habitat use. However, since fish in the order Siluriformes can expel foreign objects such as tags from their body cavity, the utility of telemetry technology may be limited for Channel Catfish. This study aimed to determine (1) how quickly Channel Catfish reject tags that were surgically implanted into the body cavity, (2) if surgical implantation of transmitter tags causes mortality, and (3) what surgical method is best to minimize tag rejection and/or mortality.

Methods: Three surgical trials were conducted on Channel Catfish ($n = 24$) using two tag implantation methods: a nontethered method, in which the tag was freely implanted into the body cavity, and a tethered method, where the tag was attached to the pectoral girdle. Fish were observed in the lab for 30 days for trials 1 and 2 and 225 days for trial 3 following tag implantation.

Result: No complete tag rejections occurred during any of the three experimental trials. However, all five tethered fish experienced mortality during trial 3 (58–221 days postsurgery). Necropsies indicated that the tethered tagging method led to septicaemia infections and internal lacerations from the tether, which were not observed in the nontethered fish. Tags in the nontethered fish were in the process of being absorbed into the intestinal tract, which over time might have led to tag rejection.

Conclusion: While rejection is possibly the end point of the nontethered tagging method, our results suggest it is nevertheless the better tagging method for Channel Catfish given higher survival.

KEYWORDS

Channel Catfish, internal tag, tag retention, telemetry

INTRODUCTION

Channel Catfish *Ictalurus punctatus* are an ecologically important species that also has significant commercial and recreational fishery use throughout their range, with a large maximum size and long life span (Stewart and Watkinson 2004; Siddons et al. 2016). Telemetry studies can provide crucial information to fisheries managers for decision making, allowing observation of the movement patterns of fish in their natural environment. Telemetry data are also vital for understanding how fish use their habitat (Rudolfsen et al. 2021; Brownscombe et al. 2022), including locations and timing of spawning (Gutowsky et al. 2020; Watkinson et al. 2021), whether fish are successfully using fish passage structure (Larinier et al. 2005; Silva et al. 2018; Enders et al. 2019), and to study movement of fish populations within a watershed (Ebner and Thiem 2009; Turner et al. 2021; Brownscombe et al. 2022).

In general, acoustic telemetry studies require a transmitter (tag) to be surgically implanted into the fish's body cavity, which transmits a unique identification code at a preprogrammed interval. Receivers are placed into the water body, and if the tag transmits within the detection range of the receiver, the receiver detects and decodes the transmission, recording the unique code number, time, and date of the encounter. However, if a fish dies or loses the tag after being released, it is difficult to evaluate whether mortality occurred or if the fish simply left the monitored area (D'Amico et al. 2021). Tag expulsion is uncommon for most fish species but is a common occurrence in catfishes (order Siluriformes), with the process being documented for Channel Catfish (Summerfelt and Mosier 1984; Siegwarth and Pitlo 1999), African Catfish (also known as Sampa) *Heterobranchus longifilis* (Baras and Westerloppe 1999), Mekong Giant Catfish *Pangasianodon gigas* (Mitamura et al. 2006), Blue Catfish *Ictalurus furcatus* (Holbrook et al. 2012; Gerber et al. 2019), and Brown Bullhead *Ameiurus nebulosus* (Sakaris et al. 2005). Therefore, the use of telemetry may be limited for Channel Catfish and other Siluriformes given their ability to expel foreign items implanted into their body cavity.

Previous studies in which Channel Catfish were surgically implanted with tags and released experienced large numbers of fish loss (i.e., mortality or tag rejection within days to months; Enders et al. 2019; Hansen et al. 2022). However, it was difficult to confirm whether the fish in these two studies experienced mortality, moved out of the study area, or expelled their tags (Summerfelt and Mosier 1984; Marty and Summerfelt 1986; Enders et al. 2019). Several processes of tag rejection were noted by Marty and Summerfelt (1986), including transintestinal expulsion, body wall expulsion via the incision site, and expulsion via a separate rupture through the body wall. Marty and Summerfelt (1986) described transintestinal expulsion as the process of connective tissue growing around the tag in response to the foreign object. Once the tag was fully encapsulated in fibrous tissue, it was engulfed by the intestine and expelled through the anus. To prevent expulsion, several studies have tethered the tag to a solid body structure: the pectoral girdle (Siegwarth and Pitlo 1999; Holbrook et al. 2012; Enders et al. 2019; Hansen et al. 2022). Siegwarth and Pitlo (1999), Enders et al. (2019), and Hansen et al. (2022) conducted their studies on wild-caught and released Channel Catfish, which made it more difficult to assess when and how mortality or tag rejection occurred. Siegwarth and Pitlo (1999) attempted recapturing the fish using radiotelemetry by pinpointing tag locations. However, of 41 individuals tagged, 6 tags were found without evidence of a fish, 13 fish were found dead, and 13 tags were never located. Holbrook et al. (2012) assessed tag retention on 15 tethered and 15 nontethered Blue Catfish that were held for 244 days in tanks. Within each treatment group, tags were expelled in 6 and 10 fish, respectively, ranging from 23 to 243 days postsurgery. While Siegwarth and Pitlo (1999) recommended tethering to the pectoral girdle to ensure tag retention, Holbrook et al. (2012) concluded that tethering was not ideal for tag retention as tethered fish experienced internal tissue and organ damage from both the tag and the tether, while nontethered fish showed no negative physiological response to the tag beyond rejection (Holbrook et al. 2012).

The purpose of this study was to determine whether two different tag implantation methods showed differences in tag rejection or mortality in Channel Catfish. Specifically, we assessed tag rejection and mortality in both the short term (within 30 days) and the long term (within 225 days postsurgery) in fish held in tanks and monitored daily. The first method was a nontethered implantation in which the tag was freely implanted in the body cavity. The nontethered method used in this study is similar to acoustic tag implantation in other fish species (Gerber et al. 2019; Gutowsky et al. 2020; Watkinson et al. 2021). In contrast, the tag was attached to the cleithrum (i.e., pectoral girdle) in the tethered method.

Impact statement

This research adds to the body of literature assessing tag retention in catfishes, a family of fish that are able to expel foreign objects from their body cavity. Specifically, this study assessed whether tethering a tag to a solid internal structure, such as a bone, impacts tag retention or increases mortality in Channel Catfish.

The tethered method is similar to the methods used by Enders et al. (2019) and Hansen et al. (2022), adapted from Siegwarth and Pitlo (1999).

METHODS

Fish collection

Channel Catfish were collected via barbless hook angling from the Red River in Lockport, Manitoba, Canada, across three sampling events. There were 10 Channel Catfish that were collected for trial 1 (spring) on May 18, 2021 (F1–F10), four Channel Catfish were collected for trial 2 (summer) on July 29–30, 2021 (F11–F14), albeit increased fishing effort (1.5 days of effort), and 10 Channel Catfish were collected (F15–F24) during trial 3 (fall) on September 8, 2021. During each trial, half of the fish were subsequently tagged using the tethered method and the other half using the nontethered method.

Surgery preparation

Surgical tag implantations were performed in situ at the capture site to simulate a field-tagging environment. A four-person crew performed the surgeries, including the same experienced surgeon (~10 years of experience conducting internal tagging surgeries on a number of fish species) for all surgeries, two assistants, and a data recorder. Individual fish were held in an aerated live well prior to the surgeries. Immediately prior to surgery, individuals were placed into a portable electrosedation unit (PES unit; Smith Root, Vancouver, Washington) for 3 s and electroimmobilized using the settings 15 Hz, 25% duty cycle, and 100 V. The fish were then weighed (kg) using a hanging scale, measured (total and fork lengths in centimeters), and placed on a wetted surgery board with their lateral–ventral surface facing the surgeon. Surgery time was recorded from time of incision until the final suture was placed. Each fish was externally tagged with a T-bar tag for identification. The tag and all other surgical equipment were soaked in a disinfectant (Betadine; Avrio Health L.P., New York, New York) prior to use and rinsed in filtered water prior to each surgery. Surgical gloves were worn to reduce the risk of infection. Throughout all surgeries, the surgery board, fish body, and gills were continuously irrigated with ambient river water using a wash bottle. Following surgeries, fish were placed back into the live well to recover. Once all surgeries were completed and fish recovered, they were transferred to Fisheries and Oceans Canada's Freshwater Institute Aquatic Holding Facility (Winnipeg, Manitoba) for long-term observations. A 975-L transfer tank was maintained at ambient river temperature (±2°C) with ice and aerated with air stones for the 1-h drive.

Protocols for surgery methods

Nontethered method

The initial step of the nontethered method of surgical implantation was a small incision (approximately 20 mm) using a scalpel starting ~0.5 cm from the tip of the left pectoral fin (looking anteriorly from the dorsal fin; Figure 1A) as outlined in Gerber et al. (2019). The incision was carefully made through skin and muscle into the coelomic cavity, avoiding any major organs (e.g., intestine). After the incision was made, the tag (model V-16; InnovaSea Systems, Boston, Massachusetts) was implanted directly into the body cavity. The incision was then closed using three interrupted sutures (PDS Plus 3-0, 22 mm 1/2c round bodied, antibacterial sutures; Ethicon, Raritan, New Jersey).

Tethered method

In comparison, the tethered method (adapted from Siegwarth and Pitlo 1999) required a larger incision (approximately 38 mm) starting at the tip of the left pectoral fin (Figure 1B). Prior to surgery, a sterilized plastic cap was fixed on the tag to tether the tag to the pectoral girdle using a polyamide, pseudo-monofilament, nonabsorbable thread (size 0; B. Braun Surgical, Rubi, Spain). A 15-cm-long 18G needle containing the sterilized polyamide thread was guided through the abdomen in a plastic tube to the cleithrum bone of the pectoral girdle in the gill cavity. A spoon was placed inside the gill cavity to prevent the needle from damaging the gills. The thread was pulled through the open opercula, and the other end of the thread was put through the plastic cap of the tag. The tag was then placed inside the body cavity, the needle removed from one end of the thread, and the other end was placed into the needle. The needle was reinserted into the body cavity, and the thread was guided to the opposite side of the cleithrum bone and through to the gill cavity. The two ends of the thread were then tied off to hold the tag in place, now attached to the cleithrum. The incision was then closed with three interrupted sutures.

Fish holding and necropsy

Channel Catfish from trials 1 and 2 were held for 30 days in a flow-through tank with dechlorinated water and aeration.

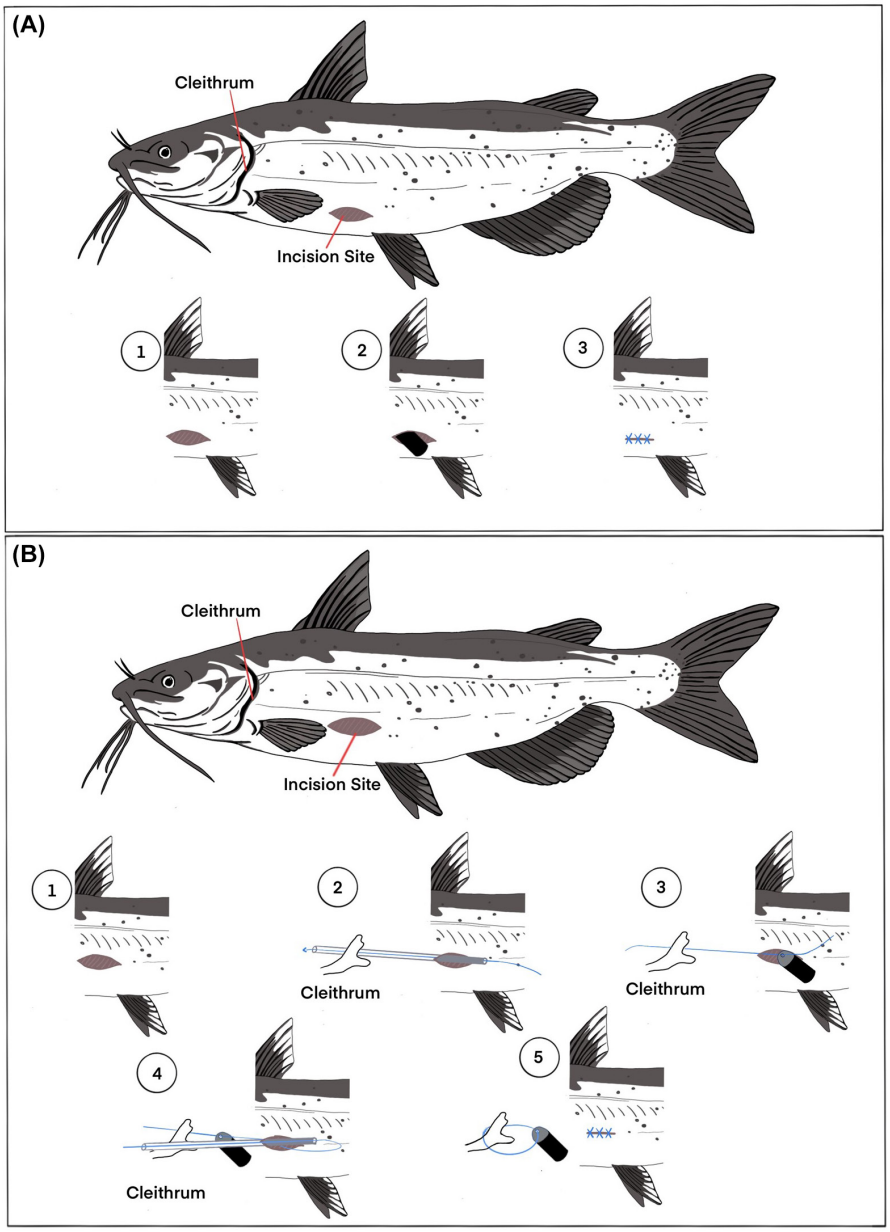

FIGURE 1 A visual representation of the surgical methods used for implanting acoustic tags into Channel Catfish. Panel (A) shows the nontethered tagging method, with (step 1) a small incision (approximately 20 mm) using a scalpel starting 0.6 cm from the tip of the pectoral fin (at number 4.5 on a clock face, with the dorsal fin as number 12 and the ventral side at number 6 on a clock face) as outlined in Gerber et al. (2019), (step 2) the tag implanted directly into the body cavity, and (step 3) the incision then closed using three interrupted sutures. Panel (B) shows the tethered tagging method (adapted from Siegwarth and Pitlo 1999), with (step 1) a slightly larger incision of approximately 38 mm using a scalpel starting at the tip of the pectoral fin (at number 4 on a clock face). Using a 15-cm-long 18G needle (step 2), a sterilized polyamide nylon suture was guided through the abdomen in a plastic tube to the cleithrum bone of the pectoral girdle in the gill cavity. A spoon was placed inside the gill cavity to prevent the needle puncturing the gills. The thread was pulled through the open opercula, the other end of the nylon was threaded through the plastic cap of the tag, (step 3) the tag was then placed inside the body cavity, and the needle was removed. The needle (step 4) was reinserted into the body cavity, and the thread was guided to the opposite side of the cleithrum bone and through to the gill cavity, with each end of the nylon thread tied off to hold the tag in place, and (step 5) the incision was then closed with three interrupted sutures.

For the first 3 weeks, the temperature was maintained at the same level as at the capture location. During the final week of holding, the temperature was adjusted to acclimate the fish to the temperature of the river, with the intent of returning fish to the site of capture. Dissolved oxygen concentration and water temperature were checked daily to ensure maintenance of correct levels. Dissolved oxygen was maintained above 80% saturation. Fish were fed daily on a diet of commercial pellets (Pacific Plus 5 mm; EWOS, Bergen, Norway) at a rate of 0.5% of the total tank mass. Due to high survival

(11 of 14 individuals across trials 1 and 2, with two of the three mortalities not related to the tag) and no tag rejection during the first two trials, trial 3 was conducted over an extended duration (225 days) to assess longer-term tag rejection and mortality. During this extended holding period in trial 3, water temperature was adjusted daily (following the initial 3-week tank acclimation) to reflect the water temperature profile of the capture location (±1°C). Due to reduced feeding on commercial pellets several weeks into holding, trial 3 fish were switched to a diet of ~370 g/day of previously frozen Cisco *Coregonus artedi* and Emerald Shiner *Notropis atherinoides* to reflect their natural diet, which improved feeding.

At the end of the 1-month holding period for trials 1 and 2, we investigated the tag placement, tag retention, incision healing, and sutures. For this investigation, two fish of each tagging method were euthanized using a buffered MS-222 (tricaine methanesulfonate) solution (300–450 mg/L MS-222; Sigma-Aldrich, St. Louis, Missouri; 600–900 mg/L sodium bicarbonate). The fish were then weighed (kg), and total and fork lengths (cm) were measured. First, the sutures were observed to determine if any had failed. Subsequently, a ~10-×~10-cm window of tissue was removed at the incision site. The incision site was probed to determine if it had fully healed, and the window of tissue was then stored in 95% ethanol for future histological analysis. The placement of the tag in the body cavity was noted and observed for any sign of encapsulation in mesentery. If encapsulation had occurred, the organ that the tag was encapsulated in was noted and removed along with the tag (still encapsulated) and stored in 95% ethanol. Photographs of sutures, incision site, and tag placement were taken throughout all investigations for later analyses. Subsequently, the progress of tag rejection was assigned a transintestinal expulsion score (TES) similar to Marty and Summerfelt (1986). Since the individuals in this experiment did not fully expel the tags, the TES was modified from Marty and Summerfelt (1986) to reflect the state of expulsion observed in these trials with the following TES categories: 1 = approximately half the tag was encapsulated in connective tissue, 2 = the tag is fully encapsulated in connective tissue, 3 = the tag is fully encapsulated in connective tissue and associated with the digestive tract, 4 = the tag is completely inside the digestive tract, and 5 = the tag is expelled from the intestine via the anus (Marty and Summerfelt 1986). Scores denoted with 0.5 indicate that the tag was in between two phases of expulsion.

Released fish

The six Channel Catfish not necropsied in trial 1 were returned to the capture location 30 days postsurgery. Their movement was further studied using an array of telemetry receivers installed in the Lake Winnipeg basin (Enders et al. 2019; Hansen et al. 2022). We assumed the date of mortality or tag rejection corresponded with (1) the date of final tag detection following documented upstream movement or (2) the initial date a continual downstream movement began and was followed by no further tag detections or repeated detections suggesting the tag had stopped moving. Any form of upstream movement was assumed to indicate a live fish that had not rejected its tag. Fish from trials 2 and 3 were not released because all fish in these trials were euthanized for necropsy or experienced mortality during the holding period.

Analysis

Differences in TES scores were analyzed in R and RStudio (R version 4.0.2, R Core Team 2020; RStudio version 1.3.1056, Posit Team 2020) using an ANOVA to test for differences between tagging methods. Fish that experienced non-tagging-related mortality (i.e., jumping out of tank) and those released following trial 1 were excluded as no necropsy was performed, leaving $n = 16$ fish for the statistical analysis. In analysis, p-values of 0.05 were deemed significant.

RESULTS

General health of Channel Catfish postsurgery

All Channel Catfish ($n = 24$) recovered from surgery and appeared to be feeding and swimming normally in the holding tank the day after surgery. Six Channel Catfish from trial 1 (three tethered and three nontethered) were returned to the capture location in good condition, with fully healed incision sites and no noticeable infection around the tether. Biological, tagging method, and mortality data for individual fish can be found in Table S1 in the Supplementary Material in the online version of this article.

Healing status of incision site and sutures

Incisions for both tagging methods showed signs of healing, ranging from partially healed (5 mm still unhealed) to fully healed. All but one suture were fully intact without any ripping. It was noted during necropsies that all 11 fish subjected to the tethered implantation method showed signs of inflammation and the tether cutting into the flesh inside the opercula at the tether site on the cleithrum (Figure 2).

FIGURE 2 Necropsy of Channel Catfish tagged with the tethered method, showing the tether position near the opercula and the associated damage to the skin and muscle over the cleithrum near the knot location.

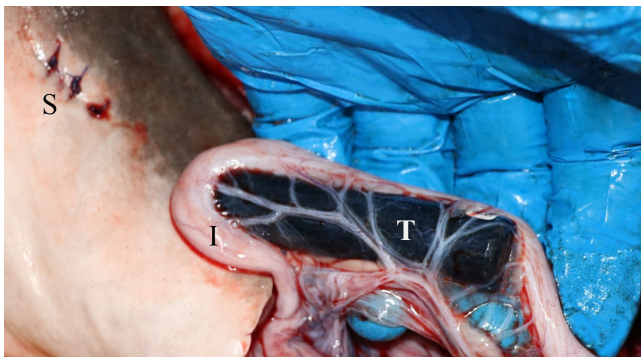

FIGURE 3 Necropsy on Channel Catfish tagged with the nontethered method, showing the tag (T) fully encapsulated in fibrous connective tissue associated with the intestine (I). Also visible is the incision site showing fully sealed sutures (S).

Tag retention and expulsion status

Necropsies revealed that all but one fish appeared to be at various stages of transintestinal expulsion of the tag; however, no tag was fully expelled. The tags in all but one fish were encapsulated in mesentery tissue and closely associated with the intestine in both tag treatments (Figure 3). Notably, the encapsulated tag in F13 (nontethered method) associated with the intestine had migrated posteriorly along the digestive tract, while the tag in F22 (tethered method) was found to be embedded into the lumen of the intestine (i.e., partially entered the intestine). There was no difference in TES score between the tagging methods (ANOVA: $F_{1,14}=4.12$, $p=0.06$), with the mean ± standard error TES score for the tethered and nontethered methods being 2.1 ± 0.4 and 2.8 ± 0.1, respectively (Figure 4). Tags implanted with the nontethered method had generally progressed posteriorly along the intestinal tract, while tags from the tethered method remained anchored to the pectoral girdle and relatively in the initial implant location. Fish F17 (tethered) was the only individual not to be in the process of transintestinal expulsion. Instead, the tag in this fish was half expelled through the septum into the gill chamber, causing broken and misshapen gill lamellae and an imprint of the tag within the gills.

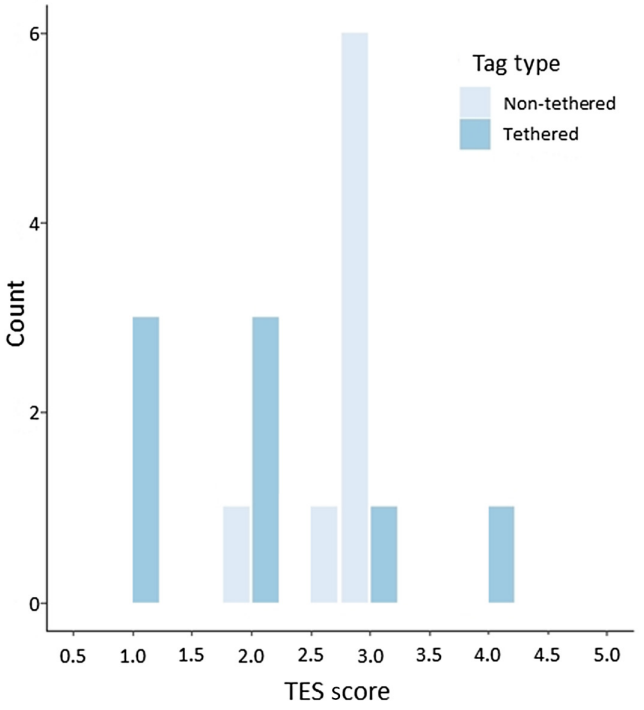

FIGURE 4 Transintestinal expulsion score (TES) for Channel Catfish from fish that were euthanized for necropsy of both tagging methods (tethered and nontethered). A TES score from 0 to 5 was assigned based on the level of transintestinal expulsion seen upon investigation. The TES scores are as follows: 0 = no encapsulation present, tag free floating; 1 = approximately half the tag encapsulated in connective tissue; 2 = tag fully encapsulated in connective tissue; 3 = tag fully encapsulated in connective tissue and associated with the digestive tract; 4 = tag completely inside the digestive tract; and 5 = tag expelled from the intestine via the anus. Scores denoted with 0.5 indicate the tag was in between two phases of expulsion.

Released fish

A telemetry study was ongoing in the Red River and Lake Winnipeg watershed for several years (Enders et al. 2019; Hansen et al. 2022), and the six fish that were released were recorded on receivers within this study array. Results showed that these fish were detected moving throughout the Lake Winnipeg watershed since release. As of June 2023, when annual receiver downloads were completed, movement from two of the six fish was still being detected (one of each tagging method; 749 days postsurgery), with fish losses (i.e., mortality or tag rejection) seen 59 and 531 days postsurgery for two tethered fish and 122 and 538 days postsurgery for two nontethered fish.

Mortalities

All 10 Channel Catfish from trial 1 survived throughout the 1-month experiment. During trial 2, three of four fish experienced mortality, only one of which was possibly associated with the tag implantation. Upon necropsy of this fish, which died 31 days postsurgery, a small hole in the tissue and an internal infection was noted near the tagging site. Therefore, this mortality was likely due to poor incision healing following implantation of the tag. The other two mortalities were caused by one fish jumping out of the experimental tank (tethered; 1 day postsurgery) and the other fish (nontethered; 3 days postsurgery) was found to have a liver injury incurred during surgery, which was observed during necropsy. This mortality would be unrelated to the tag itself and instead due to a laceration during the initial incision. Similar to trial 1, all 10 fish survived during the initial 1-month holding period of trial 3, which prompted a longer holding period. However, all five tethered fish died prior to the end of trial 3, while no mortalities occurred amongst the five nontethered fish. The first tethered fish mortality occurred 58 days after surgery, while the majority of mortalities occurred just before the experiment ended, 225 days postsurgery. Three fish were found deceased 221 days postsurgery, while another mortality was found the next day. The study was concluded 225 days postsurgery, following discussion with the Freshwater Institute Animal Care Committee veterinarian. The remaining five nontethered fish were euthanized and sent to the Government of Manitoba Veterinary Diagnostic Services Laboratory along with the previous mortalities (kept frozen for later assessment) for necropsy and histology examination to determine the causes of death and possible health effects of the tagging.

Necropsy and histology findings

The necropsies performed on trial 3 fish found that the main cause of death for the tethered fish was septicaemia and internal tissue damage caused by the tethering of the tag. The tether caused lacerations to organs of several fish, while in other fish the tether attached via mesentery membrane to the intestine or other organs, such as the gall bladder. For example, the necropsy conducted by the Government of Manitoba Veterinary Diagnostic Services Laboratory on F19 (tethered method), which died 58 days postsurgery, revealed signs of internal bleeding from an unknown cause, likely associated with the tether of the tag damaging organs. The sutures were fully healed, and the tether site did not appear infected. However, the swim bladder was also attached to the body wall near the surgery site. It is possible that the swim bladder attached to the body wall via scar tissue during the healing process and could potentially have contributed to the mortality. The attachment of the tether to the tissue was found to cause a buildup of fibrous connective tissue, which in several cases appeared to be either impacting organ function or causing degeneration of the tissue, likely leading to organ failure. For fish F22, where the tethered tag was found to be in the process of entering the lumen of the intestine, the presence of the tether prevented the full rejection of the tag via the anus, causing a blockage in the intestinal tract. The attachment point of the tether externally to the cleithrum in the opercula opening did not fully heal for any of the tethered fish but instead created "draining tracts" from the gills into the coelomic cavity inside the fish, leading to fibrinous peritonitis, and was the main cause of the septicemia infections of the fish.

Necropsies found that most fish still had fatty deposits and good body condition, indicating that holding had not had major impacts on their health. However, all fish appeared to have developed holding-related issues (i.e., increased parasite loads, fin damage), which were not considered detrimental to overall health or a contribution to mortality in tethered fish.

DISCUSSION

The findings from this study suggested that the method of tethering internal tags to the cleithrum as conducted by Enders et al. (2019) and Hansen et al. (2022), based on methods by Siegwarth and Pitlo (1999), generally leads to a shorter survival period than the tag rejection period for the nontethered method. Of the nine tethered fish that were not euthanized for necropsies, only two fish had tags last longer than 221 days postsurgery, with one fish tracked for 531 days postsurgery and the other fish still being tracked 749 days postsurgery. Conversely, only one nontethered fish was lost in less than 225 days postsurgery (122 days) when excluding fish euthanized for necropsy, while one fish was tracked 538 days before it was lost, and the last fish was still being tracked 741 days postsurgery. Comparing these results to the fish tagged by Hansen et al. (2022) shows a similar short time frame for tethered fish loss, with the mean number of days a field-tagged fish was tracked being 187 days (SE = 15). However, even this may be an overestimate as only 4 of the 161 fish tagged in that study displayed any upstream movement, which was a key indication of fish loss for our released fish. Siegwarth and Pitlo (1999) saw means of 297 and 137 days of tag retention postsurgery for their tethering techniques, with 6 of their 41 tagged fish being tracked for 300 days or more. Three fish were necropsied in the Siegwarth and Pitlo (1999) study, which, similar to our study and

Holbrook et al. (2012), found that the tag had become attached to the mesentery tissue of the gut.

Based on the TES scores for the necropsied fish and the fact that all fish showed some sign of tag rejection, it is likely that Channel Catfish tagged via both implantation methods were in the process of rejecting the tag via transintestinal expulsion. Likely, the tags were in the process of being pushed through the intestinal wall, which would then be moved by peristalsis through the gut and expelled via the anus for a nontethered tag (Baras and Westerloppe 1999). Unlike similar studies observing tag expulsion in fish from the order Siluriformes (Marty and Summerfelt 1986; Baras and Westerloppe 1999), no fish in the current study showed tag expulsion by means of the incision site or via body wall ruptures; however, one tag was in the process of being rejected out the gill chamber near the tether site. Our findings suggest that the tethered implantation method may prevent complete transintestinal expulsion; however, mortality occurred in all fish held long term in trial 3 and two of the released tethered fish were lost within 2 years of surgical implantation. All fish with tethered tag implants had developed septicemia, and the majority showed signs of internal tissue damage and degeneration caused by the tether. While necropsies revealed that mortalities were due to septicemia infections, it is likely that the damage to or blockage of the gut from partial absorption of tags into the intestinal tract would have caused mortality in the long term in tethered fish as they would have been unable to complete the tag rejection process.

Significant tissue damage was found during necropsy of fish subjected to the tethered tagging method, including open wounds where the tether was attached to the cleithrum and damage to internal organs. While differences in behavior were not noticed during this study for fish being held, it is possible that released fish displayed differing behavior. Interestingly, Enders et al. (2019) and Hansen et al. (2022) reported small home ranges for tethered Channel Catfish, 3.4–101.3 km and 66 km, respectively. While all three of the tethered Channel Catfish in this study showed similar small areas of distribution in the lower Red River and south basin of Lake Winnipeg, one nontethered fish undertook the longest migration of any of the tagged-and-released Channel Catfish observed in the frame of the Lake Winnipeg fish movement study. The fish moved south from the release site at Lockport, Manitoba, Canada, traveling up the Red River to Fargo, North Dakota, USA, a distance of ~412 km, before returning to Canada and moving into Lake Winnipeg and into the Winnipeg River, an ~515-km return trip.

While the tethering methods in this study followed those used by Enders et al. (2019) and Hansen et al. (2022), adapted from Siegwarth and Pitlo (1999), the location of the tether caused significant issues for healing and caused damage to internal organs. The length of the internal section of the tether was designed to allow the tag to sit toward the anterior of the body cavity to avoid the tag impacting major organs. While a shorter tether, which would move the tag closer to cleithrum and organs and away from the intestines may lead to less internal tissue damage, nontethered tagging is the suggested method to reduce internal injuries related to tag insertion as the external knot on the tether was also found to be a factor in fish mortalities, regardless of additional damage from the internal portion of the tether. Future experiments could also be conducted where fish are held in waters of similar quality to the Channel Catfish's natural habitat (i.e., the Red River), which would allow the observation of retention or rejection status in a water quality that is similar to what the fish would experience during field tagging. Under these circumstances, the incision may not heal as well as was seen in this study, possibly leading to a higher risk of infections, which may subsequently result in tag expulsion via the incision if healing is slower.

This study and prior studies (Summerfelt and Mosier 1984; Marty and Summerfelt 1986) found that tag rejection in Channel Catfish is a common occurrence, with results from the current study being similar to findings reported by Holbrook et al. (2012) for Blue Catfish in that tethered tags appear to hinder long-term survival as necropsies conducted on fish from both tagging methods showed significant impacts on fish health due to tethering. Ultimately, nontethered tags may be an option for shorter-term studies with proper a priori preparation on sample sizes needed to account for fish loss that would provide meaningful results. Indeed, our findings agree with Neely et al. (2021) that suggest that researchers focusing on species from the order Siluriformes need to identify other long-term options for studying movements. The use of T-bar tags appear to be a suitable option for long-term mark–recapture studies in Channel Catfish, with long retention times found by Spurgeon et al. (2020). A combination of nontethered acoustic telemetry tagging for shorter-term movement data combined with T-bar tags for longer term survival data may be a good option for future studies for fish in the order Siluriformes.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

Data is available in Table S1 in the Supplementary Material.

ETHICS STATEMENT

Study methods were carried out in accordance with approved animal use protocols from Fisheries and Oceans Canada (Freshwater Institute Animal Care Committee AUP-2021-022) and the University of Nebraska–Lincoln (Project ID: 1208). Fish were collected and held under a Government of Manitoba Live Fish Handling Permit (Permit No. 24205236).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.