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BRIEF COMMUNICATION

Long-term retention of acoustic telemetry transmitters in temperate predators revealed by predation tags implanted in wild prey fish

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Abstract

Bloater *Coregonus hoyi* (n = 48) were implanted with V9DT-2x predation transmitters and monitored on 105 acoustic receivers in eastern Lake Ontario for >6 months. Twenty-three predation events were observed, with predator retention of tags ranging from ≤1 to ≥194 days and 30% of retentions lasting >150 days. Long tag retention times raise concerns for acoustic telemetry analysis and the health of piscivorous predators retaining tags.

KEYWORDS

acoustic telemetry, coregonid, gut evacuation, Laurentian Great Lakes, predation, tag retention

Acoustic telemetry is a rapidly evolving field that has revolutionised the ability to track aquatic organisms and enabled studying aspects of aquatic ecology that were previously elusive (Hussey *et al*., 2015). Technological advances such as increased battery power and the miniaturisation of transmitters (hereafter tags) have facilitated the study of increasingly smaller species and individuals, broadening the scope of telemetry studies (Cooke *et al*., 2013; Hussey *et al*., 2015). As acoustic telemetry has grown in popularity, a number of studies have been aimed at common technical issues associated with detection efficiency and receiver performance (Huveneers *et al*., 2016; Kessel *et al*., 2014), false detections (Simpfendorfer *et al*., 2015) and tagging effects (Cooke *et al*., 2011). Nevertheless, relatively limited acoustic telemetry literature exists addressing predation of tagged fish due to the difficulty determining when predation events occur (Gibson *et al*., 2015; Romine *et al*., 2014). Assumptions that the telemetered individual has not died or fallen prey can place a significant bias on how we interpret results and the conclusions that we ultimately draw.

Until recently, predation events have primarily been determined through identifying suspect movement patterns based on what is assumed to be normal prey behaviour or using ancillary sensor data (*e.g*., temperature or depth; Thorstad *et al*., 2011; Thorstad *et al*., 2012; Buchanan *et al*., 2013). Development of predation tags that can detect the occurrence of predation facilitates a more straightforward ability to separate detections of the intended study animal from a predator that has consumed the tagged study animal (Halfyard *et al*., 2017). Predation tags developed by Vemco Ltd. (www.vemco.com) contain a biopolymer that dissolves in the stomach of a predator resulting in a change from a pre-predation transmission to a post-predation transmission that can be identified when the tag is detected on nearby receivers.

Tag retention time is the time between the observed predation event and the observed time when the tag has travelled through the predators gastrointestinal (GI) tract and subsequently been excreted by the predator (Halfyard *et al*., 2017). Current estimates of tag retention times are largely based on a limited number of studies testing prototype predation tags (Halfyard *et al*., 2017), evaluating gut evacuation rates (Schultz *et al*., 2015) and testing the viability of intragastric tagging (placement of a transmitter into the stomach cavity *via* the mouth; Winger & Walsh, 2001). Halfyard *et al*. (2017) conducted testing for initial prototypes of the Vemco predation tags that consisted of laboratory trials where tagged prey [rainbow trout *Oncorhynchus mykiss* (Walbaum 1792) and yellow perch *Perca flavescens* (Mitchill 1814)] were fed to captive largemouth bass *Micropterus salmoides* (Lacépède 1802). Halfyard *et al*. (2017) observed tag retention times ranging from 31.9 to 276.0 h with a mean (± SD) of 66.5 ± 6.9 h and 75.6 ± 22.0 h in trials for the first and second generation tags, respectively. Schultz *et al*. (2015) fed tagged dead Chinook salmon *Oncorhynchus tshawytscha* (Walbaum 1792) to striped bass *Morone saxatilis* (Walbaum 1792) in the wild and observed shorter tag retention times ranging from 28.8 to 64.8 h with a mean (± SD) of 43.2 ± 11.8 h. However, longer tag retention times of up to 47 days (mean 29 days) were observed by Thorstad *et al*. (2012) following consumption of Atlantic salmon *Salmo salar* L. 1758 smolts by predators. Intragastric tagging studies have been performed on a wide variety of species including several salmonids, sharks, eels and Atlantic cod *Gadus morhua* L. 1758 (Brunnschweiler, 2009; Keefer *et al*., 2004; Winger & Walsh, 2001). Retention times in these studies are generally longer (weeks to months) although measures are often taken to prevent regurgitation of tags (*e.g*., fitting the tag with surgical tubing to increase roughness). Keefer *et al*. (2004) reported a maximum retention time of 70 days in Chinook salmon intra-gastrically tagged with radio telemetry tags although tagging occurred during spawning migration when the salmon were not feeding. Winger and Walsh (2001) and Cottrill *et al*. (2006) reported even longer retention times of *c*. 3 months in Atlantic cod and American eel *Anguilla rostrata* (LeSueur 1817), respectively. Additionally, tag retention time is influenced by biological and environmental factors such as species, fish size, tag size, feeding frequency and water temperature (Schultz *et al*., 2015; Winger & Walsh, 2001). Understanding retention time of consumed tags is important for the accurate analysis of acoustic telemetry data because it can help differentiate between the behaviour of the study animal and an unknown predator. By incorporating predation tags, this study aimed to investigate the longevity and variability in tag retention time to better inform past and future research of the potential implications of tag retention in predators.

A total of 48 bloater *Coregonus hoyi* (Milner 1874) reared at the Ontario Ministry of Natural Resources and Forestry (OMNRF) White Lake Fish Culture Station (www.ontario.ca/page/visit-fish-culture-station) were tagged with acoustic tags on 6 November, 2018. Bloater are a small bodied deep-water forage fish that link deep benthic production with a wide variety of higher trophic level piscivores in Laurentian Great Lakes food webs (Eshenroder *et al*., 2016). Tagged bloater ranged in mass from 61 to 119 g (mean ± SD = 89.7 ± 13.6 g) and in fork length from 172 to 215 mm (mean ± SD = 191.6 ± 9.3 mm). Fish were anesthetised in a buffered solution of 400 mg l^{-1} MS-222 and a V9DT-2X tag (31.5 mm length × 9 mm diameter; 3.0 g weight in water; nominal delay 210 s; estimated battery life 360 days; Vemco Inc.) designed to detect predation events was surgically implanted following methods described in Klinard *et al*. (2018). Surgery lasted *c*. 120–150 s and fish were monitored daily for *c*. 2 weeks following surgery during which they exhibited no visible signs of distress.

An acoustic array of 105 acoustic receivers (69 kHz VR2W receivers; Vemco Inc.) spanning *c*. 375 km^2 was deployed in June 2018 in the St. Lawrence Channel of eastern Lake Ontario (43° 55.307 N, 76° 31.715 W). Tagged bloater were released at two locations near the east and west ends of the receiver array on November 19, 2018 and monitored until the array was downloaded on 4 June, 2019. Of the 48 tagged bloater, 47 were detected following their release into eastern Lake Ontario. Throughout the 7 month detection period, 23 tags (49%) switched from pre-predation transmissions to post-predation transmissions, indicating consumption by a predator. Six bloater appeared to die shortly after (<24 h) release based on constant detection at the same location for the remainder of the study; a movement pattern inconsistent with that of live fish. A total of 18 fish did not have any post-predation detections with detection periods ranging from <1 to 7 days (mean ± SD = 1.4 ± 1.8 days). Presumably these fish left the array or died in a location where they could not be detected.

For the 23 individuals that were consumed by predators, pre-predation detections of tagged bloater occurred for a mean (± SD) of 2.7 ± 1.8 days after release with the first post-predation detection occurring 5.5 ± 5.2 days after release (Table 1). Signal lag is the time between consumption of the tagged fish by a predator and the time at which the tag switches signal transmission (Halfyard *et al*., 2017). As demonstrated by the difference between the mean pre-predation and post-predation time periods, signal lag can range from several hours to several days and probably varies by predator species, detection frequency and environmental and biological conditions. Halfyard *et al*. (2017) observed signal lag times of less than *c*. 29 h and less than *c*. 9 h for >90% of the first and second generation prototype tags, respectively; however, the sensitivity of the signalling trigger for the V9 tags used in this study was modified from both prototype tags. Furthermore, the prey used in this study (bloater) were larger than those in Halfyard *et al*. (2017) and thus, presented more tissue to digest before the tag was exposed to the acidic environment of the predators stomach, lengthening the signal lag period.

The period that predator movements were monitored varied among individuals due to different post-predation detections recorded on receivers in the array. Instances where the predator did not have prolonged detections (*i.e*., several days) were probably a result of it swimming or expelling the tag beyond the detection range of the receivers. On average, predators were detected for 76.7 ± 78.8 days (Table 1). Tag retention times of predators varied from ≤1 to ≥194 days with 30% (*n* = 7) of predators that consumed tagged fish exhibiting retention times >150 days (Table 1 and Figure 1). Six predators expelled the tag within the array as evident by consistent detections at a constant location for the remainder of the study; thus, there are more precise retention times for these individuals (fish 4–9; Table 1 and Figures 1 and 2e,f). Three tags switched from pre-predation to post-predation transmissions but showed no movement of the predator because the tags had already been expelled upon the first post-predation detections (fish 1–3; Table 1 and Figure 1). The remaining 14 fish were detected until the array was downloaded on 4 June 2019, resulting in detection periods of up to 194 days (fish 10–23; Table 1 and Figure 1 and 2a–d). During the time that the tag remained inside the digestive tract of the predator, individuals exhibited largescale movements throughout the lake and travelled an average (± SD) maximum distance of 24.8 ± 48.6 km (Table 1 and Figure 2).

In comparison with other studies that report retention time of telemetry tags following consumption by a predator or gastric insertion, the retention times observed in this study are much longer. Studies based on predation of acoustically tagged fish report retention times ranging from 1 to 47 days (Halfyard *et al*., 2017; Schultz *et al*., 2015; Thorstad *et al*., 2012) whereas studies implementing intragastric insertion of radio tags often result in retention times ranging from several days to *c*. 3 months (Cottrill *et al*., 2006; Winger & Walsh, 2001). The larger acoustic tags used in this study, 31.5 × 9 mm, compared with

TABLE 1 Summary of all tagged *Coregonus hoyi* that were consumed by predators (n = 23) during the detection period of 19 November 2018–4 June 2019

Fish number	DAL fish[a]	Day first pred. det.[b]	DAL predator[c]	Retention time (days)[d]	Max. dist. pred. (km)[e]
1	1	–	–	≤1	–
2	1	–	–	≤2	–
3	1	–	–	≤5	–
4	6	6	2	2	6.3
5	4	4	11	11	11.6
6	2	3	12	12	17.3
7	7	11	36	36	9.4
8	2	2	94	94–99	17.4
9	1	2	168	168	17.3
10	2	3	1	≥1	9.7
11	1	11	≤1	≥1	10.9
12	2	2	5	≥5	8.9
13	6	6	15	≥15	17.4
14	1	12	16	≥16	18.4
15	2	2	18	≥18	14.1
16	5	5	39	≥39	12.0
17	2	2	42	≥42	9.8
18	2	23	151	≥151	230.4
19	2	2	169	≥169	17.8
20	2	3	182	≥182	23.8
21	5	5	186	≥186	23.8
22	2	2	189	≥189	8.6
23	2	3	194	≥194	11.6
Mean ± SD	2.7 ± 1.8	5.5 ± 5.2	76.7 ± 78.8	–	24.8 ± 48.6

[a]The number of days from release to final detection.
[b]The number of days since release that the first post-predation detection occurred.
[c]The number of days between the first and last detection of the predator.
[d]Retention time is the number of days the tag was inside the gastrointestinal tract of the predator based on the day of the first predator detection, where ≥ and ≤ represent uncertainty due to a lack of consistent detection data.
[e]The maximum distance that the predator was detected from the release location of tagged fish.

those used by Halfyard *et al.* (2017) 12.7 × 4.3 × 5.6 mm, and Schultz *et al.* (2015), 13.5 × 6.1 mm, may have presented difficulties for the predator passing the tag through the GI tract. However, it should be noted that the ratios of tag mass: body mass did not exceed 5% and were within acceptable limits for this species (Klinard *et al.*, 2018).

An established relationship exists between water temperature and metabolic rate in fishes and thus, higher water temperatures can lead to faster tag excretion (Halfyard *et al.*, 2017; Schultz *et al.*, 2015). All 23 of the tagged fish in our study were consumed when water temperatures were between 5 and 8°C and with potentially decreased feeding and digestion rates over winter. At the time of the receiver download in June, water temperature was *c.* 7°C and 14 fish had yet to expel the tags based on the available detection data. Other sources of variability in retention times may include prey and predator species, fish size and feeding patterns but require additional study.

The long retention times observed in this study also raise concerns for the health of predators that consume tagged prey fish, even within acceptable tag-size limits. A tag lodged in the GI tract of a predator may impede the passage of digested food, alter regular foraging patterns, affect reproductive ability and ultimately result in death (Bridger & Booth, 2003). Armstrong and Rawlings (1993) observed reduced feeding by Atlantic salmon parr following intra-gastric tagging. Similarly, Adams *et al.* (1998) and Jepsen *et al.* (2001) documented decreased feeding and growth of intra-gastrically tagged Chinook salmon. Although the predators are displaying 2D movement that may be perceived as normal behaviour, there is little information on the potential detrimental effects of tag retention.

The main concerns interpreting these results include differentiating between a mobile predator and an expelled tag, the occurrence of false positives and uncertainty associated with maximum retention times. The large-scale movements (range 6.3–230.4 km) observed post-predation are characteristic of several of the abundant predators in Lake Ontario (*e.g.*, lake trout *Salvelinus namaycush* (Walbaum 1782) and Chinook salmon) and not bloater (current authors, unpubl. Data; Figure 2). Post-predation detections that span several km and change through time are unlikely to be a function of the detection range in the system, which is >600 m at 80% detection efficiency for a V9 tag (Klinard *et al.*, 2019). Abrupt changes from widespread post-predation movements to consistent detections at one location for an extended period suggest expulsion of the tag (Figure 2e,f). Halfyard *et al.* (2017) conducted false-positive trials on prototypes of predation tags to quantify the rate of tags reporting a predation event when the tagged fish was not consumed or died unrelated to consumption. Initial evidence suggested that the prototype predation tags could correctly identify predation events on timelines suitable for most research (*i.e.*, signal lag was short enough that there was ample opportunity for tags to trigger prior to being excreted), were not likely to falsely identify predation events and would provide the ability to identify mortality unrelated to predation given the tag is stationary shortly post-mortem (Halfyard *et al.*, 2017). Current models of the Vemco predation tags have undergone further scrutiny and development and have a high trigger success rate (Dale Webber, pers. comm.). Estimates of maximum retention time presented in this study are limited by the spatial extent of the receiver array and a lack of detections when predators exit the array in this large lake. Improved spatial receiver coverage of the lake could allow for more precise retention time estimates.

The highly variable and extensive tag retention times presented in this study highlight issues concerning assumptions made during the filtering and analysis of acoustic telemetry data. Tag retention times that are longer than previously conceived (*i.e.*, digestion–egestion rates) can further contribute to the difficulty of identifying predation of a tagged fish (without predation tags). As such, extended tag retention may increase the likelihood that incorrect assumptions are made about detections originating from the intended study animal and result in improper conclusions. In addition to the effect retention time has on telemetry data analysis, it is important to consider how tag

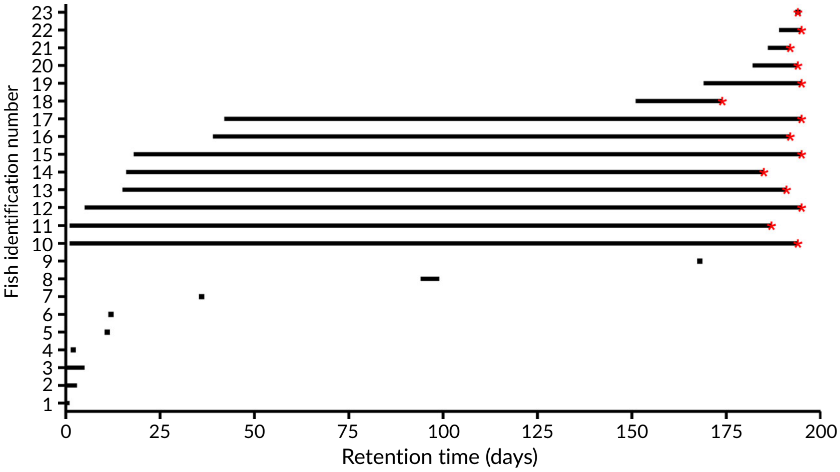

FIGURE 1 Retention time in days for each tagged *Coregonus hoyi* that was consumed by a predator (n = 23). Retention time is presented as a range for most individuals due to uncertainty associated with the time the tag remained inside the predator from a lack of consistent detection data. *, Indication that the receiver array was downloaded and thus, retention time may extend beyond this period but is unknown

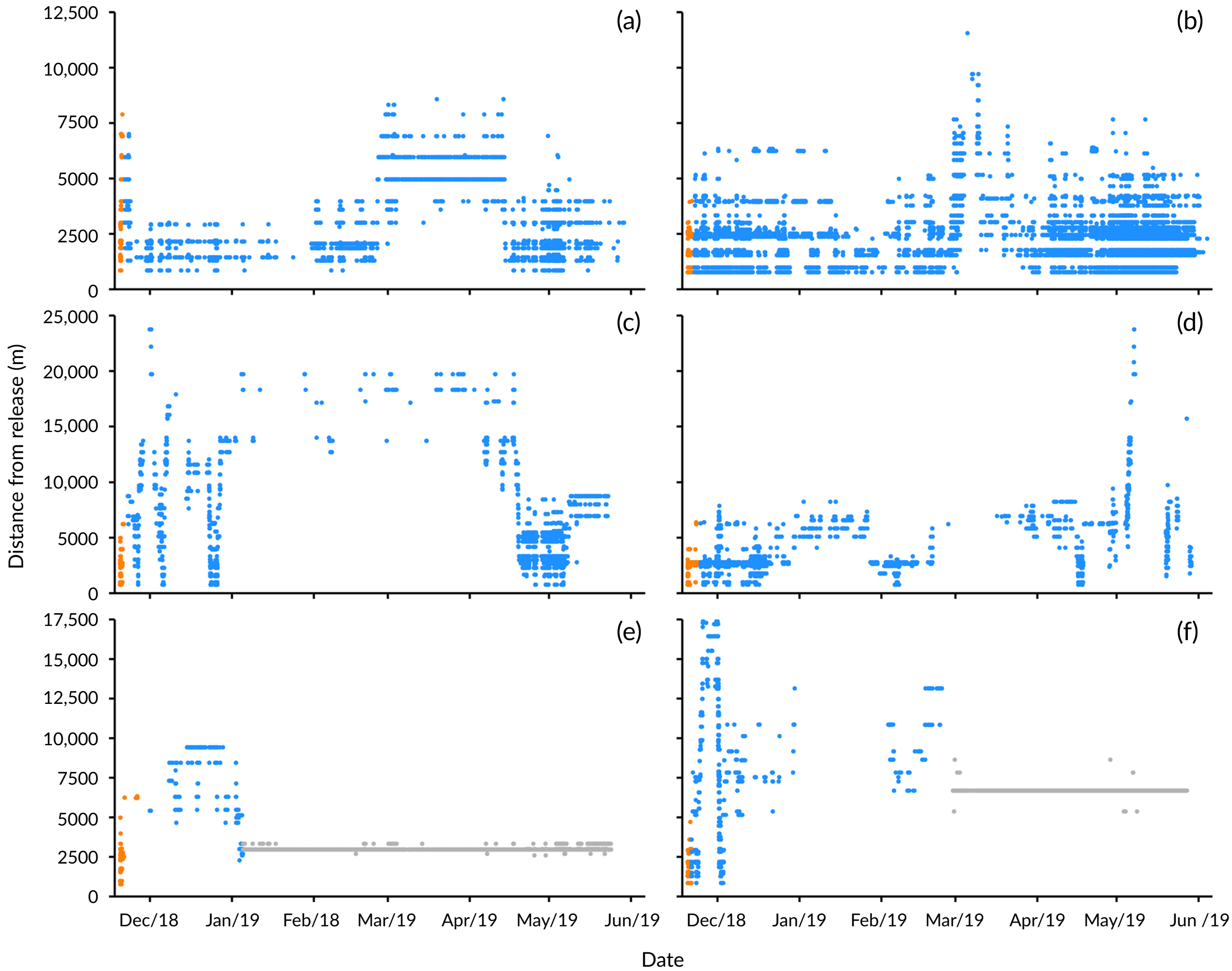

FIGURE 2 Detection profiles from 19 November 2018–4 June 2019 for six tagged *Coregonus hoyi* that were consumed by predators; (a) fish number 22, (b) fish number 23, (c) fish number 20, (d) fish number 21, (e) fish number 7 and (f) fish number 8. ●, Pre-predation; ●, post-predation; ●, excreted tag detections

retention affects the health and wellbeing of piscivorous predators that are unable to expel these tags for extended periods of time. Future studies should explore further the potential energetic or health detriments associated with long-term tag retention and consideration should be given as to whether tag size–retention could bias interpretation of the study animal in instances were predation tags are not used. Furthermore, understanding the ecology and spatial patterns (*e.g.*, migration, spawning, depth use) of the study species as well as other species in the study system can aid in distinguishing between detections of the tagged species and a predator. In instances where it is difficult or not possible to distinguish between detection patterns, predation tags provide the ability to identify predation events.

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ETHICS STATEMENT

This research was carried out with the approval of the University of Windsor Animal Care Committee (AUPP 15–21).

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