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Neil P. Rude
Southern Illinois University Carbondale

Gregory Whitledge
Southern Illinois University Carbondale, gwhit@siu.edu

Quinton E. Phelps

Shawn Hirst
Illinois Department of Natural Resources

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Long-term PIT and T-bar anchor tag retention rates in adult muskellunge

Neil P. Rude, Gregory W. Whitledge*, and Quinton E. Phelps
Fisheries and Illinois Aquaculture Center
Department of Zoology
Southern Illinois University
Carbondale, IL 62901-6511, USA

Shawn Hirst
Illinois Department of Natural Resources
Murphysboro, IL 62966, USA

*Corresponding author: gwhit@siu.edu

Abstract. – Mark-recapture studies require knowledge of tag retention rates specific to tag types, fish species and size, and study duration. We determined the probability of tag loss for passive integrated transponder (PIT) tags implanted into dorsal musculature, T-bar anchor tags attached to dorsal pterygiophores, and loss of both tags in relation to years post-tagging for double-marked adult muskellunge *Esox masquinongy* over a 10 year period. We also used PIT tags as a benchmark to assess the interactive effects of fish length at tagging, sex, and years post-tagging on T-bar anchor tag loss rates. Only five instances of PIT tag loss were identified; the calculated probability of a fish losing its PIT tag was consistently < 1.0% for up to 10 years post-tagging. The probability of T-bar anchor tag loss by muskellunge was related to the number of years post-tagging and total length of fish at tagging. T-bar anchor tag loss rate one year after tagging was 6.5%. Individuals < 750 mm total length at tagging had anchor tag loss rates < 10% for up to 6 years after tagging. However, the proportion of fish losing T-bar anchor tags steadily increased with increasing years post-tagging (~30% after 6 years) for larger muskellunge. Fish gender did not influence probability of T-bar anchor tag loss. Our results indicate that T-bar anchor tags are best suited for short-term applications (≤ 1 year duration) involving adult muskellunge. We recommend use of PIT tags for longer-term tagging studies, particularly for muskellunge > 750 mm total length.

Tagging and marking techniques are frequently used in fisheries investigations to obtain information on population parameters, movement patterns, individual growth, and to distinguish different groups of fish (Guy et al. 1996). Choosing an appropriate tagging or marking technique is guided by several factors, including study design and objectives, cost, and characteristics of the fish being tagged; additionally, tags or marks should not affect fish behavior, growth, or survival and should have high retention and recognition rates (Guy et al. 1996). For tagging studies involving muskellunge *Esox masquinongy*, tag longevity and the ability to detect tags non-lethally are particularly important given that catch and release is a common practice in muskellunge fisheries, many of which are managed for trophy fish, and muskellunge are seldom sacrificed during sampling (Younk et al. 2010).

Several recent studies have evaluated retention rates of tags applied to muskellunge, including passive integrated transponder (PIT) and visible implant elastomer (VIE) tags (Wagner et al. 2007; Jennings et al. 2009; Younk et al. 2010). Short-term (overwinter) retention of VIE tags was 100% in fingerling muskellunge, but recognition of VIE tags in adult fish marked at age-0 was poor (Younk et al. 2010). High retention rates (>90% and often >95%) of PIT tags for age-0 and adult muskellunge over time periods ≥ 1 year have been observed, particularly for PIT tags implanted into dorsal musculature (Wagner et al. 2007; Jennings et al. 2009; Younk et al. 2010). While PIT tags appear to be suitable for long-term tagging studies requiring recognition of individual muskellunge across a broad range of fish sizes, the tags can only be detected with a transceiver. If data from angler-caught fish are sought, T-bar anchor tags may be a better choice given their visibility to anglers. T-bar anchor tags may also be valuable as a secondary tagging method to indicate PIT tag presence or to enable recognition of an individual fish in the event of PIT tag loss.

The utility of T-bar anchor tags for mark-recapture studies depends on their retention rate over time, which has been shown to be highly variable in a variety of fish species (Waldman et al. 1991; Muoneke 1992; Clugston 1996; Buzby and Deegan 1999; Gurtin et al. 1999; Walsh and Winkelman 2002; Livings et al. 2007). Differences in anchor tag retention rates among fish species and over time demonstrate the need for tag retention rate estimates specific to fish species and study durations. Few published studies have assessed T-bar anchor tag retention rates in esocid fishes. Pierce and Tomcko (1993) determined that northern pike *Esox lucius* T-bar anchor tag retention was >98% one year after tagging. Similarly, Weeks and Hansen (2009) reported that T-bar anchor tag retention rate averaged 97.9% for muskellunge in northern Wisconsin lakes one year after tagging. However, reliability of anchor tags applied to muskellunge over longer time periods has not been evaluated. The objectives of this study were to determine the probability of PIT tag loss, T-bar anchor tag loss, and loss of both tags in relation to years post-tagging for double-marked adult muskellunge over a 10 year period. We also assessed the interactive effects of fish length at tagging, sex, and years post-tagging on T-bar anchor tag loss rates.

Methods

The study was conducted in Kinkaid Lake, a 1,113-ha reservoir located in Jackson County in southern Illinois (37.7976°N, 89.4315°W). Kinkaid Lake receives annual stockings of juvenile muskellunge (~275 mm total length (TL)) at densities of 1.80-2.47 individuals/ha; the extent of natural reproduction is unknown. Adult muskellunge were collected annually from 1999-2010 on weekdays within a 1-2 week period during spring (late March to mid-April) using 1.22-m x 1.83-m frame trap nets (15.24-m lead, 25.4-mm mesh bar measure). Nets were set at 12 to 18 fixed locations throughout the lake during each year. All fish were removed from nets daily. Total length of each captured muskellunge was measured (nearest mm) and gender was determined for each fish based on the shape of the urogenital papilla (LeBeau and Pageau 1989; Brenden et al. 2006).

Upon initial capture, each fish was implanted with a DESTRON 125-kHz PIT tag (12.0 x 2.1 mm; Destron Fearing, South St. Paul, MN) in the dorsal musculature (below the dorsal fin) and also tagged with an algaecide-treated, individually numbered, 76-mm T-bar anchor tag (Floy Tag and Mfg., Inc., Seattle, Washington; product number FD-68B) affixed through the dorsal pterygiophores. Successful implantation of a functional PIT tag was confirmed in the field by scanning the fish with a portable hand-held tag reader. The same tagging crew was used throughout the study. Each fish was released into the lake after confirming successful placement of tags. Individuals captured during 2000-2010 were visually examined for T-bar anchor tags and scanned to determine presence or absence of a functioning PIT tag. Fish bearing neither a PIT tag nor a T-bar anchor tag were tagged as described above and released. T-bar anchor tag and PIT tag numbers were recorded for recaptured individuals. Unreadable T-bar anchor tags were counted as lost tags. If either PIT or T-bar anchor tags were lost (as evidenced by the presence of only one tag type) or if T-bar anchor tags were unreadable, the lost or unreadable tag was replaced. Recaptured fish were then released back into the lake.

Recapture histories of individual fish were compiled over the course of the study to determine the probability of PIT tag loss, T-bar anchor tag loss, and loss of both tags in relation to years post-tagging for double-marked adult muskellunge (Seber 1982). PIT and T-bar anchor tag presence or absence histories were developed for each recaptured muskellunge during each year following their initial tagging date (including year 0 for fish recaptured during the year in which they were tagged). The year of PIT or T-bar anchor tag loss was recorded for fish that lost one of the tags and were recaptured within one year of a previous recapture in which both tags were still intact or within one year of tagging. For fish that did not possess one of the tags and were recaptured ≥ 2 years after tagging or ≥ 2 years after their last recapture in which they possessed both tags, years in which PIT or T-bar anchor presence or absence was unknown were recorded as missing data. For the double marking portion of the study, only data from initial tagging until loss of one of the tags were used for an individual fish; data from re-tagged individuals were not used. The probability of a fish losing a PIT tag in a given year post-tagging was calculated with the following equation from Seber (1982):

$$P_{PIT}(t) = m_{T\text{-}bar}(t) / \{m_{T\text{-}bar}(t) + m_{PIT,}\, m_{T\text{-}bar}(t)\}$$

where $P_{PIT}(t)$ is the probability of PIT tag loss, $m_{T\text{-}bar}(t)$ is the number of fish caught at time t bearing only a T-bar anchor tag, and $m_{PIT,}\, m_{T\text{-}bar}(t)$ is the number of fish caught at time t bearing both tags. Probability of T-bar anchor tag loss ($P_{T\text{-}bar}(t)$) was determined in an equivalent manner by replacing $m_{T\text{-}bar}(t)$ with $m_{PIT}(t)$ (the number of fish caught at time t bearing only a PIT tag) in the above equation. The joint probability of a fish losing both tag types in a given year post-tagging was calculated as the product of PIT and T-bar anchor tag loss probabilities.

Very low probability of PIT tag loss (<1%) for adult muskellunge enabled use of PIT tags as a reference to investigate the effects of fish length at tagging, sex, and years post-tagging on T-bar anchor tag loss rates. A T-bar anchor tag presence or absence history was compiled for each recaptured, PIT-tagged muskellunge as described in the preceding paragraph. However, replacement T-bar anchor tags implanted in fish that had previously lost their anchor tag were treated as new tagging events. Thus, data from re-tagged individuals were included in assessment of the effects of fish TL at tagging, sex, and years post-tagging on T-bar anchor tag loss.

Logistic regression was used to assess the effects of TL at tagging (mm), sex, and years post-tagging and their interactions on T-bar anchor tag loss in adult muskellunge. A second logistic regression was performed using only those effects that were significant in the first regression model. To further investigate the effect of fish size at tagging on T-bar anchor tag loss, individual fish were assigned to one of three size classes based on TL at tagging: small (< 750 mm TL), medium (751-900 mm TL), and large (> 901 mm TL). A chi-square test was used to evaluate whether the proportion of fish that lost T-bar anchor tags differed among size classes. Chi-square tests were also used to assess differences in the proportion of fish that lost T-bar anchor tags across years post-tagging within each of the three size classes of muskellunge. To graphically illustrate differences in patterns of tag loss over time among the three size classes of muskellunge, we plotted the probability of T-bar anchor tag loss predicted by the logistic regression model in relation to years post-tagging for fish of 600, 800, and 1,000 mm TL at the time of tagging. All statistical analyses were performed using SAS 9.2 (SAS Institute, Inc. Cary, NC). P-values ≤ 0.05 were considered significant for all statistical tests.

Results

A total of 2,461 muskellunge were collected and tagged, of which 841 fish were recaptured at least once during this study. Total lengths of muskellunge collected ranged from 397 mm to 1,269 mm (mean 901 mm). Male muskellunge comprised 62% of the total catch and females and immature fish were 36% and 2% of the total catch, respectively.

Calculations of tag loss rates based on double marking revealed that the probability of PIT tag loss was very low throughout the duration of this study. There were only five instances in which a recaptured fish had lost its PIT tag but retained its T-bar anchor tag. Thus, the calculated probability of a fish losing its PIT tag was < 1.0% for up to 10 years post-tagging (Table 1). The probability of a fish losing its T-bar anchor tag ≤ 1 year post-tagging was < 6%, but steadily increased with increasing years post-tagging. T-bar anchor tag losses included only two instances in which a tag was unreadable due to fouling or damage. The estimated probability of a fish losing both PIT and T-bar anchor tags was very low (< 0.2%) for each year up to 10 years post-tagging (Table 1).

Consistently high retention rates of PIT tags by adult muskellunge enabled use of PIT tags as a reference mark to subsequently assess the effects of fish size at tagging, sex, and years post-tagging on T-bar anchor tag loss rates. Logistic regression revealed that the probability of T-bar anchor tag loss by muskellunge was related to years post-tagging ($P < 0.0001$) and TL of fish at tagging ($P < 0.0001$), with the probability of tag loss increasing with increasing years post-tagging and TL of fish at tagging. Fish gender did not influence probability of T-bar anchor tag loss ($P = 0.73$). None of the interactions among years post-tagging, sex, and TL of fish at the time of tagging were significant within the model ($P > 0.21$ for each interaction term). The equation describing the probability of T-bar anchor tag loss (P(loss)) as a function of years post-tagging and TL of fish at tagging (mm) was:

$$P(\text{loss}) = e^{x} / (1 + e^{x}),$$

where $x = -6.5596 + 0.5351 \cdot \text{years post-tagging} + 0.00395 \cdot \text{TL}$. Standard errors for the intercept and coefficients for years post-tagging and TL were 0.8531, 0.0481, and 0.000913, respectively (Figure 1).

A chi-square test indicated that the proportion of fish that lost T-bar anchor tags differed among the three size classes of muskellunge that were based on TL at tagging ($X^2 = 14.3199$, $P = 0.0008$). There was no significant difference in the proportion of fish that lost T-bar anchor tags across years post-tagging for fish within the small size class ($X^2 = 14.833$, $P = 0.1383$; Table 2). The proportion of recaptured fish in the small size class that lost T-bar anchor tags was < 10% up to 6 years after tagging. However, the proportion of fish that lost T-bar anchor tags differed among years post-tagging for fish in the medium ($X^2 = 151.708$, $P < 0.0001$) and large ($X^2 = 49.5062$, $P < 0.0001$) size classes, with the proportion of fish losing tags increasing with increasing years post-tagging (Table 2).

Discussion

Consistent with published studies, our results suggest that PIT tags appear to be reliable short- or long-term tags when implanted into the dorsal muscle of muskellunge (Wagner et al. 2007; Younk et al. 2010). We documented very few instances of PIT tag loss or malfunction, as evidenced by the presence of a T-bar anchor tag (or a scar at the anchor tagging location) and non-detection of a PIT tag, in adult muskellunge. Although recaptures > 7 years after tagging were limited given the 11 year duration of this study, our results confirm that PIT tags can be retained in adult muskellunge and function for up to 10 years. Retention rates ≥ 95% for PIT tags implanted into dorsal musculature have also been reported for other fish species (Moore

1992; Daugherty and Buckmeier 2009; Dieterman and Hoxmeier 2009). Results of our double marking study and other published studies of PIT tag retention rates in dorsal muscle of muskellunge and other fish species support our use of PIT tags as a benchmark for evaluating factors influencing T-bar anchor tag loss rates.

T-bar anchor tags appear to be best suited for short-term (< 2 years) tagging studies involving adult esocids. The overall rate of T-bar anchor tag loss in this study one year following tagging (6.5%) was slightly higher than the T-bar anchor tag loss rate for muskellunge one year after tagging (2.1%) reported by Weeks and Hansen (2009). Potential reasons for the difference in T-bar anchor tag retention rates in this study and in Weeks and Hansen (2009) include differences in tags used and size distribution of tagged fish between the two studies; Weeks and Hansen (2009) tagged muskellunge > 508 mm, but no further details of the size distribution of fish sampled in their study were given. Regardless, both studies documented > 90% retention of T-bar anchor tags by muskellunge under field conditions one year after tagging. While similarly high T-bar anchor tag retention rates have been reported for some other fish species (including northern pike) one year after tagging (Clugston 1996; Pierce and Tomcko 1993; Buzby and Deegan 1999; Gurtin et al. 1999; Livings et al. 2007), other studies have observed much lower retention rates for T-bar anchor tags ≤ 1 year after tagging for some fish species (Waldman et al. 1991; Muoneke 1992; Walsh and Winkelman 2002). Collectively, results of our study, Pierce and Tomcko (1993), and Weeks and Hansen (2009) suggest that T-bar anchor tags are a viable, inexpensive alternative to PIT tags for short-term tagging studies with adult muskellunge and other esocids. Use of T-bar anchor tags also facilitates gathering information from tagged fish caught by anglers, a potentially important consideration with respect to tag choice for popular sport fish such as muskellunge.

Fish size at tagging was a significant factor influencing long-term retention rates of T-bar anchor tags by adult muskellunge, suggesting that T-bar anchor tags may not be well-suited to studies involving relatively large muskellunge. Although individuals < 750 mm TL at tagging had tag retention rates > 90% for up to 6 years after tagging, T-bar anchor tag retention rates steadily declined over time for larger muskellunge. Declining tag retention rates over time have also been observed in multi-year studies of T-bar anchor tag retention rates for other fish species (Clugston 1996; Buzby and Deegan 1999). T-bar anchor tags applied to all muskellunge in this study were 76 mm long; perhaps use of larger tags for fish > 750 mm TL may have resulted in higher tag retention rates, particularly > 1 year after tagging. Additional assessment of retention rates for larger T-bar anchor tags applied to muskellunge > 750 mm TL is recommended. In the absence of additional studies on T-bar anchor tag retention rates in adult muskellunge, we recommend that these anchor tags be used when angler reporting of tags is important or in short-term applications (≤ 1 year duration) and recommend use of PIT tags for longer-term tagging studies, particularly for muskellunge > 750 mm TL.

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Table 1. Percent probability of tag loss by adult muskellunge for PIT tags, T-bar anchor tags and both PIT and T-bar anchor tags in relation to years post-tagging.

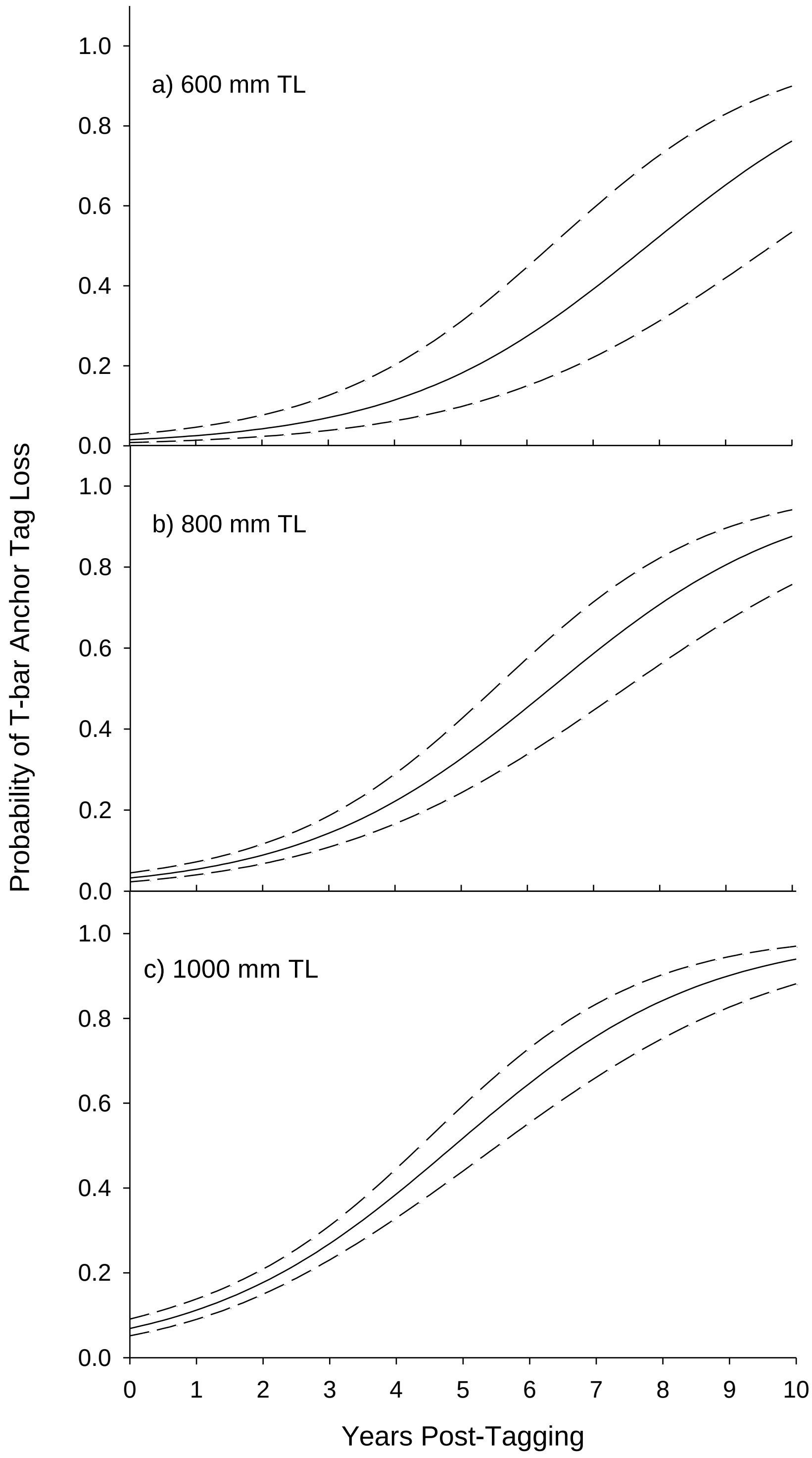
Years Post-Tagging	n	Prob. PIT Tag Loss (%)	Prob. T-Bar Loss (%)	Prob. PIT and T-Bar Loss (%)
0	695	0.00	0.58	0.00
1	488	0.44	5.97	0.03
2	318	0.37	14.51	0.05
3	206	0.62	21.95	0.14
4	107	0.00	22.43	0.00
5	60	0.00	21.67	0.00
6	24	0.00	37.50	0.00
7	6	0.00	33.33	0.00
8	5	0.00	20.00	0.00
9	1	0.00	0.00	0.00
10	2	0.00	50.00	0.00

Table 2. Percentage of muskellunge that lost T-bar anchor tags in relation to years post-tagging for fish in small (< 750 mm TL), medium, (751-900 mm TL), and large (> 901 mm TL) size classes at the time of tagging. Numbers in parentheses indicate sample sizes.

	% T-Bar Anchor Tag Loss		
Years Post-Tagging	Small	Medium	Large
0	0.83 (120)	0.00 (449)	1.32 (304)
1	4.76 (105)	5.29 (302)	8.42 (190)
2	3.79 (79)	16.43 (207)	11.76 (119)
3	9.46 (74)	23.07 (130)	18.03 (61)
4	4.55 (44)	26.76 (71)	21.74 (23)
5	0.00 (24)	27.03 (37)	26.67 (15)
6	0.00 (8)	36.36 (22)	28.57 (7)
7	25.00 (4)	0.00 (1)	33.33 (3)
8	0.00 (2)	33.33 (3)	0.00 (1)
9	0.00 (2)	.	.
10	0.00 (1)	50 (1)	.

Figure Captions

Figure 1. Predicted probability of muskellunge losing a T-bar anchor tag in relation to years post-tagging. Panels a, b, and c represent the predicted probabilities of T-bar anchor tag loss for fish of 600 mm total length (TL), 800 mm TL and 1000 mm TL, respectively. Solid lines represent predicted values and dashed lines represent upper and lower 95% confidence limits for predicted values.


Probability of T-bar Anchor Tag Loss
a) 600 mm TL
b) 800 mm TL
c) 1000 mm TL
0.0
0.2
0.4
0.6
0.8
1.0
0 1 2 3 4 5 6 7 8 9 10
Years Post-Tagging