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SPECIAL SECTION

Comparison of methods for estimating wild turkey poult survival

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Abstract

Eastern wild turkey (*Meleagris gallopavo silvestris*) population growth is driven by variation in reproduction, and poult survival is a crucial vital rate. Traditional poult survival monitoring uses flush counts of radio-tagged females, but brood flocking (when broods and females merge into larger flocks) and mark retention are potential problems with this method and can produce biased estimates. Alternatively, radio-tagging poults to estimate survival offers a potentially less-biased method if tagging and tracking poults can be conducted without adverse effects on the poults. We compared poult survival estimates derived from flush counts and from radio-tagged poults over a 56-day monitoring period during 2018–2022 in south-central Tennessee, USA. We radio-tagged 183 poults and monitored 85 broods via 2-week flush counts and observed 572 individual poults during flush counts over the 56-day monitoring period. We used known-fate survival models for the telemetry data, Lukacs survival models for the flush count data, and a modified known-fate model to estimate whether radio-tagging poults affected their survival. Two-week survival estimates from the flush count of broods, and radio-tagged poults were similar (flush count: day 0–28: 0.25, 95% CI: 0.20–0.31, day 29–56: 0.56, 95% CI: 0.36–0.76; radio-tagged: day 0–28: 0.30, 95% CI: 0.23–0.37, day 29–56: 0.68, 95% CI: 0.49–0.87). Using known-fate survival models, radio-tagged poults had similar survival rates to non-tagged poults within the brood (day 0–28: $\hat{S}_{Radio\text{-}tagged}$ = 0.15, 95% CI: 0.10–0.20 v. $\hat{S}_{Non\text{-}tagged}$ = 0.20, 95% CI: 0.16–0.23), which suggests the radio-tags did not directly affect survival. However, survival of individuals that were trapped was lower than survival of broods that were not trapped during the first 14 days. Trapping methods may need to be adjusted to limit incidental capture effects when choosing to use radio-tagged poults. Conducting flush counts every 14 days until day 56 of the brood-rearing period likely is the most cost-effective method for estimating poult survival. However, monitoring individual radio-tagged poults may yield additional information, such as cause-specific mortality, that may better inform management.

KEYWORDS

Meleagris gallopavo, methodology, poult survival, radio telemetry, southeastern United States, wild turkey

Eastern wild turkey (*Meleagris gallopavo silvestris*, hereafter, wild turkey) population growth is driven by variation in reproduction, and poult survival is a crucial reproductive parameter (Vanglider and Kurzejeski 1995, Pollentier et al. 2014a, Lehman et al. 2022, Londe et al. 2023). Both abiotic and biotic factors can influence poult survival, such as predator communities (Hughes et al. 2007), vegetation cover (Spears et al. 2005), and temperature (Nelson et al. 2022). Poult survival is a critical vital rate to estimate because it directly relates to overall recruitment, which has been identified as a factor limiting wild turkey population growth throughout the southeastern United States (Byrne et al. 2016).

Estimating poult survival and recruitment can be difficult because of the poult's rapid growth rate, brooding behavior, and ability to avoid detection (Orange et al. 2016, Chamberlain et al. 2020). For example, wild turkey poults within the first week of hatching averaged 58.2 g (SD = 15.1 g) in our study area, and at the time of capture, juveniles averaged 7,100 g (SD = 1,700 kg, J. O. Quehl, University of Tennessee, unpublished data). An increase in mass between the time of capture as a poult and the following winter as a juvenile reduces tag retention. Wild turkeys also merge into larger brood flocks (Little and Varland 1981) that can make conducting accurate counts of a given brood difficult, and is confounded with survival (S) and detection (p) in mixed broods (Flint et al. 1995, Lukacs et al. 2004). Conventionally, poult survival is measured by flushing radio-marked brooding females every 2 weeks up to 28 days post-hatching (Glidden and Austin 1975, Vander Haegen et al. 1988, Hubbard et al. 1999). Flush counts do not require individually marked poults, but the formation of brood flocks may positively bias estimates if mortality events are masked by new individuals added to the brood (Flint et al. 1995, Tsai et al. 1999). Finally, poults can be increasingly difficult to detect over time as they become more mobile with age and as vegetation matures, which can impact the accuracy of the poult survival estimates.

Thus, compounded biological and sampling issues associated with poult survival estimation may violate underlying assumptions and lead to biased estimates. Six assumptions are relevant to poult survival analyses: 1) a representative sample of the population is used in estimation, 2) survival is independent among individuals unless accounted for within the estimator, 3) radio-tags or marks do not influence the poults' fate, 4) newly tagged poults have the same survival function as previously tagged poults, 5) time of death/fate is known for individuals, though recent modeling advancements may have relaxed this assumption, and 6) censored individuals have the same probability of survival as monitored individuals (Tsai et al. 1999). One common issue with both survival estimation methods is whether poults within the same brood are related, as this non-independence can affect the variance of estimates (Bishop et al. 2010). The flush count method potentially violates assumption 5, whereby brood flocks could obscure the time of death/fate for individual poults; thus, these data need to be modeled differently to avoid positively biasing survival estimates (Orange et al. 2016). The radio-tag method does not have the same issues with brood flocks, because poults are individually marked, but assumption 5 may still be violated, as the fate can be unknown for poults whose signal is lost. Additionally, the radio-tag method may violate assumption 3 if individual poults with radio-tags have different survival functions than those without radio-tags. With flush counts, detection probability is usually assumed to be constant throughout the monitoring period. Detection probability can vary with flush counts, because vegetation present at the flush site can increase the potential for counting error as the brood matures, mobility increases, and resighting individuals becomes more difficult (Kubečka et al. 2021). Conversely, the detection of radio-tagged poults is largely unrelated to vegetation present, movement patterns (Chamberlain et al. 2020), or brood flock amalgamation (Kubečka et al. 2021).

Traditionally, poult survival with either method has been estimated over a 28-day monitoring period and used as a metric for estimating recruitment (Glidden and Austin 1975, Vander Haegen et al. 1988, Hubbard et al. 1999, Pollentier et al. 2014b, Tyl et al. 2020). Other studies have used different time frames or speculated that poult survival stabilizes after the poults learn to fly (Spears et al. 2005: 16 days, Nelson et al. 2023: 14 days). Poult survival is related to the survival of the female as the female is responsible for brood movement and detecting predators (Vander Haegen et al. 1988, Wakeling 1991). But at some point that relationship splits and the poult can survive on its own and is no longer dependent on the female for sole survival. Radio-tagged poults offer opportunities to further explore this relationship through improvements to transmitter battery life (~56 days; Burkepile et al. 2002).

Radio-tagging poults can be more intrusive (i.e., handling very young poults) and expensive (e.g., transmitter cost and technician hours for continuous monitoring) than flush counts. Both methods require radio-tagging and monitoring nesting females to document successful nesting attempts. Monitoring radio-tagged poults may yield more valuable data beyond simple survival estimates, such as finer-scale survival estimates and cause-specific mortality information (Speake et al. 1985), as researchers can track individuals less intrusively and follow individual poults, which may justify the extra expense and intrusion.

Understanding the benefits, accuracy, and precision of each method and estimating poult survival after 28 days post-hatching could be important for researchers and agency personnel as they use these data to inform management decisions. Our objectives were to 1) compare poult survival estimates from flush counts and radio-tagged poults, 2) document poult survival from 0 to 56 days post-hatching and determine when the risk of mortality for poults equals the risk of mortality for brooding females, and 3) determine if capturing and radio-tagging poults increases their risk of mortality compared with non-tagged poults. Based on a review of the literature, we hypothesized that 1) estimates of poult survival would differ between sampling methods because each method may violate different underlying assumptions related to brood flock amalgamation, impact of transmitter, and mark retention (Hubbard et al. 1999, Tsai et al. 1999), though the true survival rates are unknown; and 2) poult survival would equal survival of the brooding female after day 28 post-hatching because of increases in poult size and mobility (Vander Haegen et al. 1988, Tyl et al. 2020, Nelson et al. 2023).

STUDY AREA

Wild turkey harvest and poult-per-female ratios have declined since 2010 in portions of south-central Tennessee, USA (Byrne et al. 2016, Tennessee Hunter Toolbox 2023). Consequently, we conducted a study of wild turkey demography in Bedford, Giles, Lawrence, Maury, and Wayne counties in south-central Tennessee (Johnson et al. 2022). We established 2 study sites in each county for a total of 10 study sites (8 on private land, and 2 on public lands; Figure 1). Private lands throughout the 10 study sites totaled >29,000 ha and included >380 individual landowners. We also tracked wild turkeys at Tie Camp Wildlife Management Area (WMA, 1,325 ha) in Wayne County and Yanahli WMA

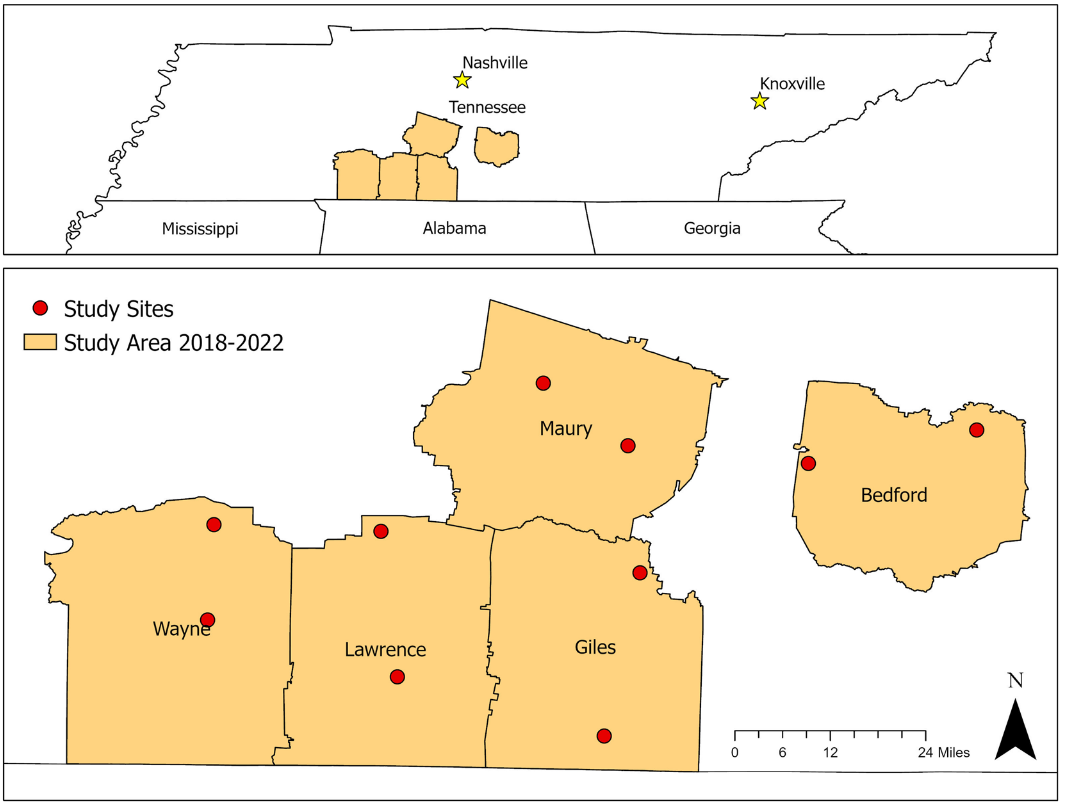

FIGURE 1 Wild turkey study sites located in Bedford, Giles, Lawrence, Maury, and Wayne counties, Tennessee, USA, 2018–2022.

(5,200 ha) in Maury County. Tie Camp WMA was managed by Bascom Southern Timber Company for timber production, and Yanahli WMA was managed for wildlife conservation and hunting opportunities.

Private and public lands included deciduous forest, pasture/hay fields, coniferous forests dominated either by planted loblolly pine (*Pinus taeda*) or naturally occurring eastern redcedar (*Juniperus virginiana*), water/human development, row crops, young forest (deciduous or coniferous trees <10 years old), and early successional communities dominated by shade-intolerant herbaceous plant species and colonizing woody species. Daily high and low temperatures for the study area during the brood-rearing season over the course of our study averaged 31°C and 17°C, respectively, and the average annual rainfall was 145.8 cm (12.1 cm per month, U.S Climate Data 2023). These compared well to long-term averages of middle Tennessee (1991–2020: mean high temp –30°C, mean low temp – 16.3°C, 138 cm of annual rainfall; United States Climate Normals 2025). Predominant soil types included Bodine cherty silt loam and gravelly silt, Gladeville rock outcrop, Ashwood, Brandon silt loam, Biffle gravelly silt loam, and Frankstown cherty silt loam (United States Department of Agriculture [USDA] 2023). The elevation and topography of our 10 study sites varied, but brood-rearing sites averaged 263 m above sea-level.

METHODS

We captured female wild turkeys using rocket netting protocols outlined by Delahunt et al. (2011) and attached a very-high-frequency (VHF, Advanced Telemetry Systems: Series A1300, Isanti, MN, USA) or GPS (Lotek: GPS PinPoint, Newmarket, Ontario, Canada) backpack-style transmitter on females from 2018 to 2022. We radio-tagged and maintained a sample of ≥10 radio-tagged females for each of the 10 study sites. We monitored females at least once per week during the nonbreeding season and every 2 to 3 days during the breeding season (1 April to 5 August) each year to document nesting activity and survival. Nest searching and monitoring followed the protocols described in Quehl et al. (2024). We classified a successfully hatched nest when at least 1 egg in the clutch was determined to be hatched based on the characteristics of eggshell fragments and membranes (Tyl et al. 2020). If a nest successfully hatched, we recorded the clutch size and number of hatched eggs, which we used to determine the original number of poults within each brood.

Brood monitoring

We monitored broods by tracking radio-tagged poults and conducting brood flush counts for radio-tagged females. We trapped poults between 1 and 8 days post-hatching by flushing the female before sunrise while they were roosting/brooding on the ground (Hubbard et al. 1999, Quehl et al. 2024). We placed all captured poults in a cooler with a heating pad to keep them warm (Hubbard et al. 1999, Spears et al. 2005). Our average handling time of captured poults was 41 minutes (range: 14–100 min, SD = 16.93 min). We radio-tagged between 1 and 6 poults within each trapped brood by suturing the transmitters (Advanced Telemetry Systems: Series A1065, Isanti, MN, USA) to their backs (Burkepile et al. 2002). Transmitters were 1.3 g and had an average life expectancy of 78 days (range: 38–97, SD = 20.4) based on field testing. The average mass of poults at capture was 57.4 g; thus, the radio-tag represented 2.3% of their mean body mass. We returned radio-tagged poults as a group to the ground-roost location to help ensure the brood reunited with the female.

We monitored each tagged poult by homing and circling to within 30 m of the brood without flushing them, similar to our methods for monitoring nest locations (Hubbard et al. 1999). If a radio-tagged poult's signal was near the female (<30 m away from the female), we assumed the radio-tagged poult was alive. If the poult's signal was >30 m from the female, we homed to the signal to determine if the poult was dead and the cause of death (Speake et al. 1985, Peoples et al. 1995). We monitored radio-tagged poults daily for the first week, every other day for weeks 2–4 (2018–2022), and twice weekly for weeks 5–8 (2021 and 2022 only). We monitored radio-tagged poults up to 91 days, but transmitter life varied after day 56 (8 weeks), so we truncated survival at 56 days to minimize the effect of transmitter failure (2018–2022). In addition to monitoring via homing, we flushed each radio-tagged female that successfully hatched a nest on days 14 and 28 post-hatching to determine the number of poults present. In 2021 and 2022, we also flushed broods on day 42 (6 weeks) and day 56 (8 weeks) post-hatching if there was a radio-tagged poult alive in the brood. We did not continue flush counts after day 56 post-hatching because females and poults became difficult to flush (i.e., the brood would scatter and run as opposed to flushing), and broods became difficult to accurately count. Unsuccessful flushes whereby the observer did not see the female were censored from the analysis unless the observer was able to determine that poults were not present (i.e., followed the female for >1,000 m without detecting poults). At each flush, we recorded the number of poults and females present, date, time, and recorded GPS coordinates of the brood location.

Data analysis

Radio-tagged survival estimates

We used known-fate models with a common day 1 data entry design using the RMARK package (Laake 2013) in Program R version 4.3.2 (R Core Team 2022) to estimate survival of radio-tagged poults (Pollentier et al. 2014b). We did not use nest survival models because our time between observations was relatively short (1–2 days during 0–28 days post-hatching). We estimated radio-tagged poult and brooding female survival over weekly time intervals and also estimated poult survival over 2-week survival intervals. We estimated weekly poult survival intervals based on radio-tags to compare to weekly brooding female survival estimates in order to evaluate when poult survival approximated female survival.

The fates of >30% of radio-tagged poults were unknown because we lost the signal and were unable to determine if the poult was dead or alive; hereafter referred to as a "missing poult." Poults likely were missing because of predation events that buried the carcass or carried the carcass out of tracking range, or by transmitter failure. We considered a poult missing if the radio signal was not heard in the vicinity of the female or the surrounding area (i.e., within 250 m). To account for missing poults, we assumed a missing radio-tagged poult was dead if no poults were observed at the day-28 flush count for the brood (55 poults were assumed dead), whereas a missing radio-tagged poult was assumed alive if ≥1 poult was observed (28 poults were assumed alive).

Flush count estimates

We estimated poult survival and detection probability from flush count data from radio-tagged females in 2-week intervals over a 56-day monitoring period using the Lukacs survival model in Program MARK version 9.0 (White and Burnham 1999, Lukacs et al. 2004). We created capture/encounter histories based on the number of poults hatched from each nest and the number of poults observed at each subsequent flush event. We only incorporated flushes when a single radio-tagged female was present, because the Lukacs et al. (2004) survival model does not account for brood mixing. Brood mixing commonly occurred, with 33.5% of the flush counts having multiple females present. We assumed that poult survival in broods with single hens present was the same as that of poults in broods with multiple hens, and we assume that brood flocks did not impact the survival of individual poults.

We tested for radio-tag effects on individual poult survival by comparing the survival of tagged vs. non-tagged poults in 2-week intervals (28-day monitoring period) using known fate models in Program R with the RMARK package (Laake 2013). To create the capture histories, we counted each hatched egg in a successful nest as a new individual that could be monitored via flush counts during 2 2-week intervals (28-day total monitoring period). Assuming 100% detection, we determined that poults were alive or dead based on the number of poults observed at each subsequent flush count. If there were multiple adult females present during a flush event, the poult count was averaged on a per-female basis. If this resulted in a non-whole number, we alternated rounding up and down (5.6% of flushes rounded down, 6.2% of flushes rounded up). Occasionally, these calculations led to the number of poults exceeding the previous count or number hatched (9.8% of flush counts). These individuals were treated as new individuals available to be monitored in subsequent flushes.

We analyzed flush count data using known-fate survival models through the 2 2-week monitoring intervals (to day 28 post-hatching) to evaluate the potential effect of trapping and radio-tagging on poult survival. We evaluated a suite of 7 *a priori* models with Akaike information criterion adjusted for sample sizes (AIC_c, Anderson and Burnham 2002) to test our hypotheses related to the potential effect of radio-tagging and trapping poults. Time interval and year were included in the model suite, along with a covariate for whether a given poult was radio-tagged (1 = tagged, 0 = non-tagged) and another covariate for whether a given poult was in a brood that we attempted to trap (1 = attempted to trap brood, 0 = did not attempt to trap brood). The key difference between these 2 covariates is that the trapped vs. non-trapped broods incorporated all poults within the brood, regardless of whether the poult was radio-tagged, whereas the other covariate was focused on whether each individual poult was radio-tagged.

For hypotheses (1) and (2), we used a standard 2-sample Z-test to test for differences between the respective groups, with $\alpha = 0.05$ for all statistical tests (Pollock et al. 1989, Sauer and Williams 1989, Lehman et al. 2000). Additionally to test for the precision of the sampling methods (hypothesis 1) we calculated coefficients of variation by dividing the standard error of the survival estimate by the estimated survival rate and multiplying it by 100 (Equation 1).

$$\text{Coefficient of variation } (CV) = \frac{SE\,(\hat{S})}{\hat{S}} \times 100 \quad (1)$$

We used an AIC_c model selection framework to select the most parsimonious model within the model suite and assess the effects of radio-tags on poult survival (Anderson and Burnham 2002). We considered models within 2 ΔAIC_c to be supported. We chose to use an 85% confidence interval for β value interpretation (i.e., CIs of β values that included zero were not supported as effects), based on simulations and recommendations by Arnold (2010). Additionally, we used 95% confidence intervals for survival estimates to interpret statistical and biological significance.

For both radio-tagged and flush count poult survival data, we tested for brood mate independence (assumption 2, Tsai et al. 1999) using the bootstrap methods outlined in Bishop et al. (2010) in Program R version 4.3.2 (R Core Team 2022).

RESULTS

We documented 120 successful nests (≥1 egg hatched) of 509 total nests (24%) during 2018–2022. The 120 successful nests had an average clutch size of 9.6 (SD = 3.7) and a hatching rate of 83.3% (SD = 24.2%). We trapped 245 poults and radio-tagged 183 during 62 successful trap-nights of 87 attempted brood captures (71.3% trap efficiency, Table 1). Out of the 120 successful nests, we tried to capture 77 different broods (64.2% of the successful nests). Of the 183 radio-tagged poults, 83 were missing throughout the study (45.3%; 28 poults were assumed to be alive, and 55 were presumed dead). We conducted 161 brood flush counts on 85 broods and observed 572 individual poults and 248 females for a poult-per-female ratio of 2.3 during 2018–2022. Multiple females were present during 54 of 161 flush attempts (33.5%), and broods were successfully flushed during 145 of 161 attempts (90.0%). We only included 116 females in the brooding female survival analysis because we were unable to relocate 4 females after hatching. Based on Bishop et al. (2010), both radio-tagged poults and flush count data produced $\hat{c}$ values > 1.2, which suggests survival among brood mates was not independent ($\hat{c}_{\text{radio-tagged}} = 2.04$, and $\hat{c}_{\text{flush-count}} = 3.00$).

Radio-tagged and flush count survival estimates

Based on the known-fate analysis of radio-tagged poults, we estimated weekly poult survival from day 0–28 as 0.27 (95% CI: 0.20–0.34) and survival from day 29–56 as 0.66 (95% CI: 0.46–0.85). Weekly poult survival was lowest during days 8–14 and greatest during days 29–35 (Table 2). Radio-tagged poult survival for days 0–7 was 0.70 (95% CI: 0.63–0.76) and increased to 0.93 (95% CI: 0.80–0.99) during days 50–56 (Figure 2, Table 2). Brooding female survival was lowest during the days 0–7 of brood rearing (Table 2). After day 28, we did not document any mortalities of brooding females, so weekly survival from day 28–56 was 1.00 (Table 2). Based on 2-sample *Z*-tests, poult survival initially differed from brooding female survival (i.e., weeks 1, 2, 3), but did not differ during the later weeks (weeks 4, 5, 7, 8) of the 56-day monitoring period (Table 2).

Two-week (14-day) radio-tagged poult survival estimates increased over time, ranging from 0.39 (Day 0–14; 95% CI: 0.32–0.46) to 0.88 (Day 43–56; 95% CI: 0.61–0.97) based on known-fate survival models (Figure 3, Table 3). Two-week interval poult survival estimates from the Lukacs survival model based on flush counts also increased over time, ranging from 0.44 (Day 0–14; 95% CI: 0.38–0.50) to 0.80 (Day 43–56; 95% CI: 0.52–0.94; Table 3). The detection probability (*p*) for the flush count data was 0.84 (95% CI: 0.73–0.92) across the 56-day

TABLE 1 Number of wild turkey hatched nests, number of brooding females, average number of poults produced per nest, number of tagged broods, number of tagged poults, and number of flushes by time period in south-central Tennessee, USA, organized by year, 2018–2022.

					Radio tagged		Flush counts				
Year	Hatched nests	No. of brooding females	No. of poults	Avg. poults produced/ nest	Tagged broods	Tagged poults (% all poults)	No. of broods	Day 14	Day 28	Day 42	Day 56
2018	26	25	165	7.2	11	29 (17.5)	19	17	18	–	–
2019	19	19	66	8.3	11	36 (54.5)	13	12	12	–	–
2020	10	10	52	8.7	5	16 (30.8)	5	4	5	–	–
2021	44	41	260	8.4	24	77 (29.6)	29	21	26	8	4
2022	21	21	184	9.2	11	25 (13.6)	19	16	15	2	1
Total	120	116	727	8.33	62	183 (25.1)	85	70	76	10	5

TABLE 2 Weekly survival estimates and associated sample sizes and standard errors of radio-tagged wild turkey poults and brooding females in south-central, Tennessee, USA, during 2018–2022. *Z*-scores and *P*-values are based on 2-sample *z*-tests for each interval comparing weekly poult survival to weekly brooding female survival.

	Poult			Brooding Female				
Days Post Hatching	$\hat{S}_{Weekly}$	*n*	*SE*	$\hat{S}_{Weekly}$	*n*	*SE*	*Z*	*p*-value
0–7	0.70	181[a]	0.03	0.95	116	0.02	−6.31	<0.01
8–14	0.51	117	0.06	0.98	110	0.01	−9.90	<0.01
15–21	0.85	53	0.05	0.99	107	0.01	−2.72	0.01
22–28	0.91	42	0.05	0.97	77	0.01	−1.73	0.08
29–35	0.96	27	0.04	1.00	11	0.00	−1.03	0.30
36–42	0.78	21	0.09	1.00	11	0.00	−2.54	0.01
43–49	0.94	16	0.06	1.00	11	0.00	−1.02	0.31
50–56	0.93	14	0.07	1.00	6	0.00	−1.04	0.30
0–28	0.27	181	0.04	0.91	116	0.03		
29–56	0.66	27	0.10	1.00	11	0.00		
0–56	0.18	183	0.04	0.91	116	0.03		

[a]Only 181 were included in the first week survival estimate because 2 poults were captured on day 8 post-hatching.

monitoring period. Coefficients of variation (*CV*) for 2-week survival estimates from flush counts averaged 10.32 (Range: 6.98–13.22), and *CV* for radio-tagged poult survival estimates averaged 9.11 (Range: 7.37–10.29, Table 3). Radio-tagged survival estimates had lower *CV*s for three of the four 2-week monitoring periods. Based on 2-sample *Z*-tests, radio-tagged and flush count estimates did not differ ($P > 0.05$) during 3 of the 4 monitoring intervals (Table 3).

Survival of tagged and non-tagged poults did not differ and was not supported as a predictor of poult survival ($\beta = -0.03$; 85% CI: −0.25–0.20). The 28-day survival estimate for tagged poults overlapped the 28-day non-tagged

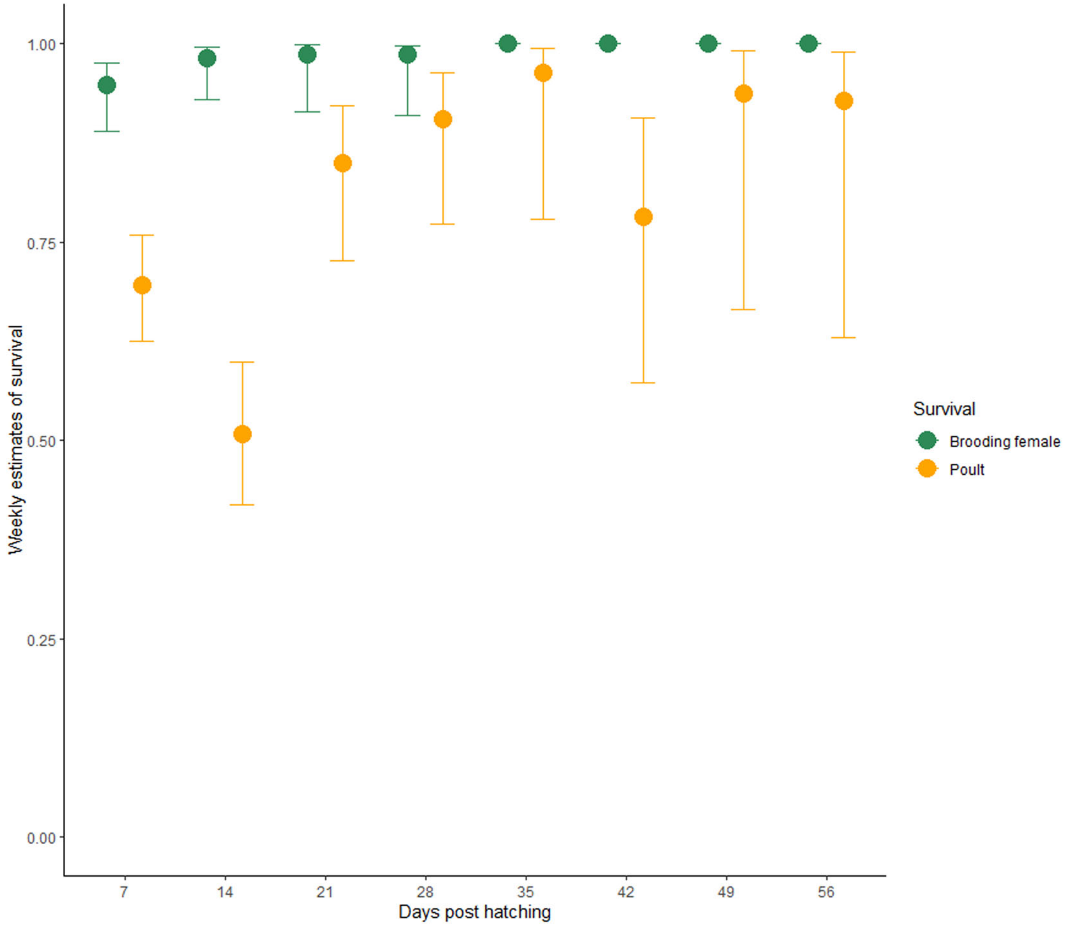

FIGURE 2 Weekly radio-tagged wild turkey poult survival estimates in south-central Tennessee, USA, 2018–2022 plotted across time in yellow. Brooding female survival over the 56-day (8-week) brood monitoring period in green. Error bars represent 95% confidence intervals derived from RMARK (Laake 2013).

poult survival estimate (Table 4). Based on 2-week intervals, tagged and non-tagged poult survival increased at similar rates throughout a 28-day monitoring period (Figure 4). The best-supported model was for an interaction between trapped broods/non-trapped broods (i.e., poults in broods that were trapped vs. broods that were not trapped) and the time interval of the flush ($\beta = -0.98$; 85% CI: −1.25 to −0.70). Trapped broods had lower overall poult survival in the first 2-week period compared with survival of non-trapped broods (Figure 5, Table 5). Survival rates did not differ between trapped broods and non-trapped broods during the 15–28 day period (Table 4).

DISCUSSION

Our radio-tagged poult survival estimates ($S_{0\text{-}28\ \text{days,2-week}} = 0.30$) were similar to or lower than estimates from previous studies using radio-tagged poults (Speake et al. 1985: 0.31, Alabama, USA; Hubbard et al. 1999: 0.52, Iowa, USA). Our flush-count estimates ($S_{0\text{-}28\ \text{days,2-week}} = 0.25$) were lower than flush-count derived survival estimates in previous studies (Vanglider et al. 1987: 0.38, Missouri, USA; Vanglider and Kurzeski 1995: 0.41, Missouri, USA; Pollentier et al. 2014b: 0.37, Wisconsin, USA; Tyl et al. 2020: 0.33, South Dakota, USA). Many of these studies

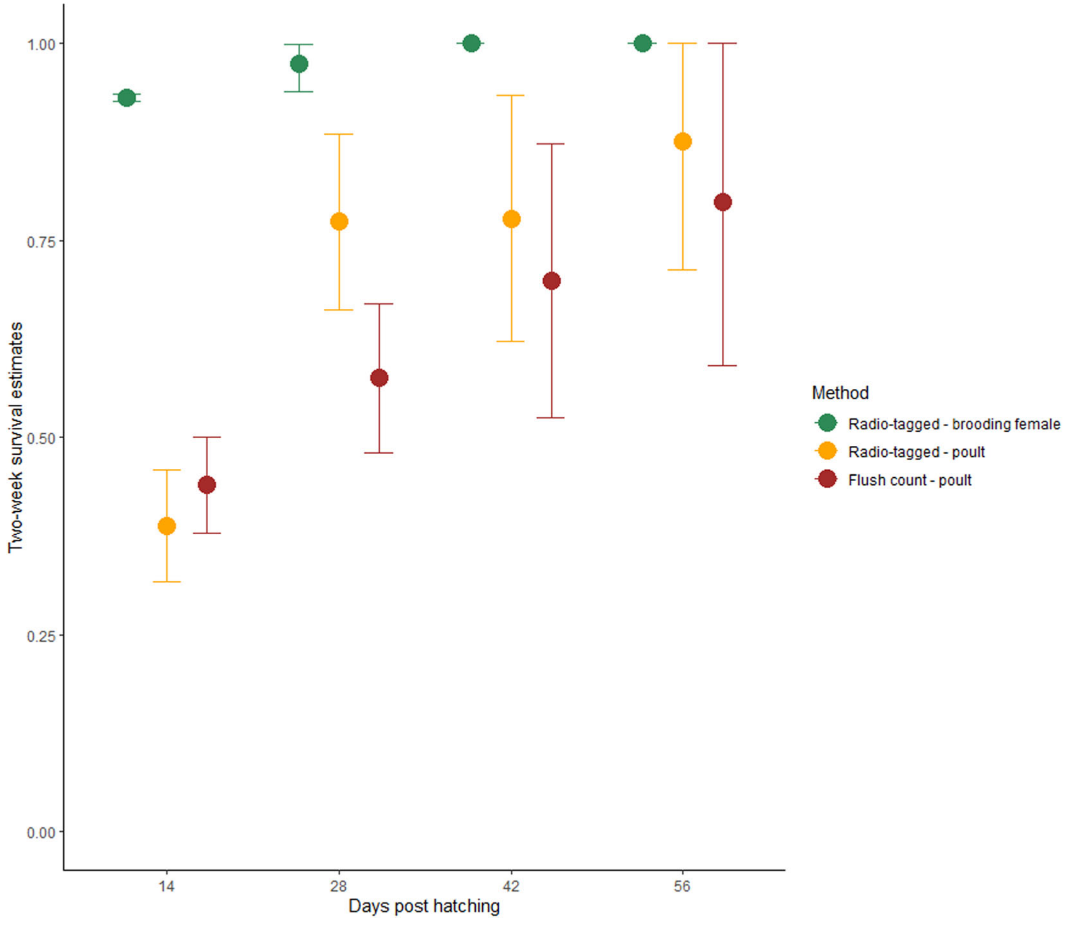

FIGURE 3 Two-week wild turkey poult survival estimates derived using flush count and radio-tagged poult data from days 0–14, 15–28, 29–42, and 43–56 post-hatching in south-central, Tennessee, USA, during 2018–2022. Two-week brooding female survival was derived from radio-tagged females and compared to both flush count and radio-tagged estimates. Error bars represent 95% confidence intervals derived from RMARK (Laake 2013).

assumed a $p = 1$, and if detection in those studies was not perfect, they would be underestimating poult survival, and the difference between our study and those would be greater. Studies prior to 2000 generally reported greater poult survival estimates than contemporary studies, consistent with increasing predator populations throughout the eastern United States (Roberts and Crimmins 2010, Troyer et al. 2014, Hody and Kayes 2018, Slate et al. 2020). Our study is the only recent southeastern United States study to report poult survival. Extending the monitoring period to 56 days was feasible under both methods using known-fate and Lukacs survival models, which may have important implications for filling critical knowledge gaps in wild turkey population dynamics.

Conventional Lukacs survival models using 2-week flush counts that included only broods with single adult females present produced similar estimates of poult survival compared to known-fate model estimates from monitoring radio-tagged poults. Survival estimates of the 2 methods differed only during the 15–28-day monitoring period. We also documented similar *CVs* with both survival estimation methods.

As hypothesized, weekly poult survival estimates were similar to weekly brooding female survival estimates after day 28 post-hatching, with poult survival only 4% lower than brooding female survival during days 29–35, as opposed to 47% lower during days 8–14. Our results were consistent with previous research that indicated poult

TABLE 3 Two-week survival estimates, estimates of 28-day survival, and coefficient of variation (*CV*) derived from flush-count data and radio-tagged poults during 2018–2022 in south-central, Tennessee, USA. *Z*-scores and *P*-values are based on 2-sample *Z*-tests for each interval comparing 2-week poult survival estimates from flush count and radio-tagged poult data.

	Flush Count				Radio-tagged					
Days Post Hatching	$\hat{S}_{2\text{-week}}$	*n*	*SE*	*CV*	$\hat{S}_{2\text{-week}}$	*n*	*SE*	*CV*	*Z*	*P*-value
0–14	0.44	73	0.03	6.98	0.39	183	0.04	9.28	−1.10	0.27
15–28	0.58	71	0.05	8.36	0.77	53	0.06	7.37	2.67	0.01
29–42	0.70	10	0.09	12.73	0.78	27	0.08	10.29	0.66	0.51
43–56	0.80	5	0.11	13.22	0.88	16	0.08	9.49	0.57	0.57
0–28	0.25	85	0.03	10.89	0.30	183	0.04	11.85	1.03	0.30
29–56	0.56	10	0.10	18.35	0.68	27	0.10	13.99	0.88	0.38
0–56	0.14	85	0.03	21.34	0.20	183	0.04	18.34	1.33	0.18

TABLE 4 Two-week poult survival estimates of radio-tagged wild turkey poults, not radio-tagged poults, poults in trapped broods, and poults in broods that were not trapped were estimated using flush count data during 2018–2022 in south-central, Tennessee, USA. We only used a 28-day monitoring period because of limited sampling sizes after day 28 post-hatching.

	Radio-tagged			Not radio-tagged			Trapped			Not trapped		
Days Post Hatching	$\hat{S}_{2\text{-week}}$	*n*	*SE*	$\hat{S}_{2\text{-week}}$	*n*	*SE*	$\hat{S}_{2\text{-week}}$	*n*	*SE*	$\hat{S}_{2\text{-week}}$	*n*	*SE*
0–14	0.31	179	0.04	0.35	520	0.02	0.28	513	0.02	0.50	186	0.04
15–28	0.47	74	0.06	0.57	229	0.03	0.57	195	0.04	0.49	110	0.05
0–28	0.15	179	0.03	0.20	520	0.02	0.16	513	0.02	0.25	186	0.03

mortality was greatest during the first 2 weeks post-hatching before they can fly (Speake et al. 1985, Hubbard et al. 1999, Nelson et al. 2023). We saw a non-linear relationship between survival and poult age, similar to Vander Haegen et al. (1988), who used flush counts up to 12 weeks post-hatching and found that survival stabilized after 28 days.

Both flush count and radio-tagged poult survival estimation methods likely violated some model assumptions. We documented strong evidence ($\hat{c}_{\text{radio-tagged}} = 2.0$, and $\hat{c}_{\text{flush-count}} = 3.0$; Bishop et al. 2010) that brood mates did not experience independent survival in either dataset (i.e., radio-tagged poults or flush count data), which violates assumption 2 (Tsai et al. 1999). Violating this assumption does not bias survival estimates, but rather the standard error, which can lead to the misinterpretation of results if $\hat{c}$ is not used to adjust standard errors (Bishop et al. 2010, Dahlgren et al. 2010). Another assumption was that radio-tags did not affect the survival of the poult (assumption 3, Tsai et al. 1999). There was no evidence that the radio-tags impacted the survival of the poults. These results are similar to pen studies of wild turkey poults (Hubbard et al. 1998, Bowman et al. 2002) and other field studies of gallinaceous birds reporting no effect of radio-tagging on survival (Ewing et al. 1994: ringed-neck pheasants, *Phasianus colchicus*; Davis et al. 1999: wood duck, *Aix sponsa*; Burkepile et al. 2002: sage grouse, *Centrocercus urophasianus*; Orange et al. 2016: northern bobwhite).

The formation of brood flocks was an issue in the flush count method that was difficult to account for, because few survival models allow mixing of individuals from different broods. Flint et al. (1995) modified a Kaplan-Meier

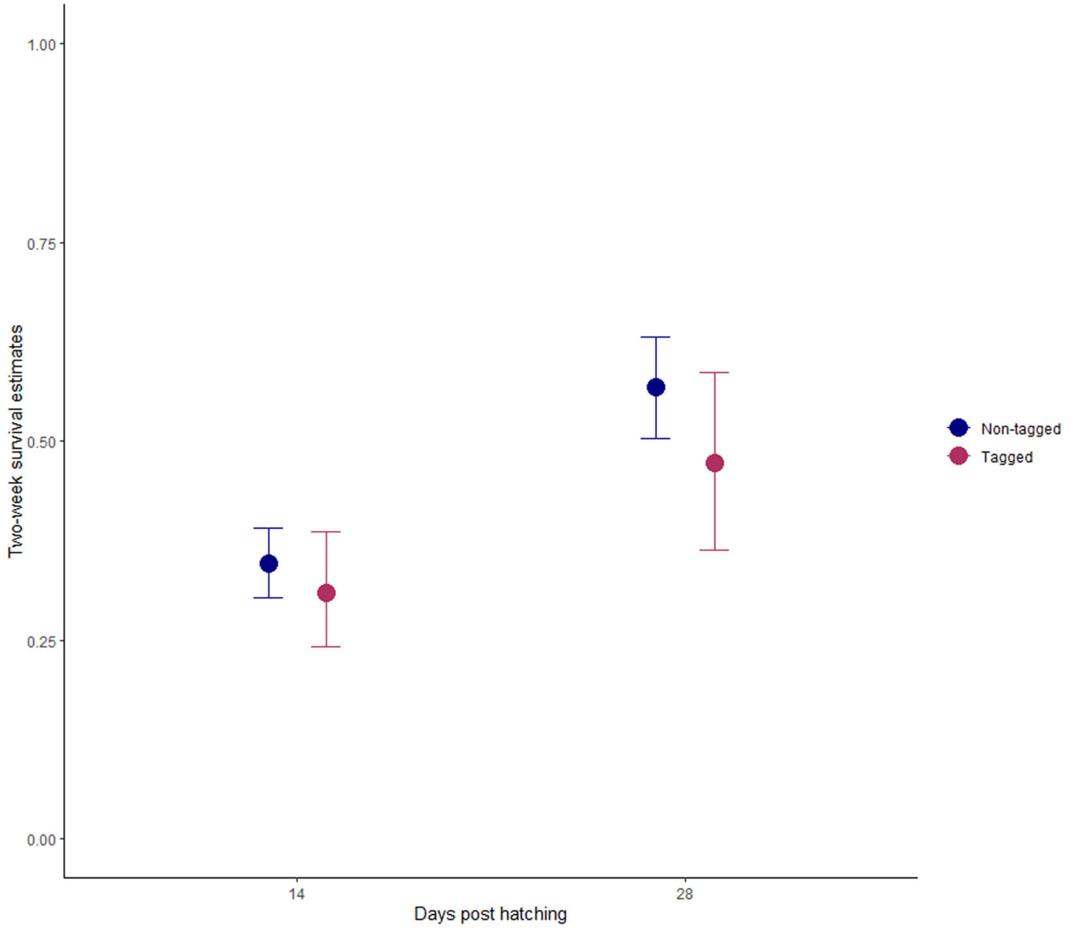

FIGURE 4 Two-week wild turkey poult survival estimates of radio-tagged poults vs. non-tagged poults using flush count data during 2018–2022 in south-central, Tennessee, USA. Error bars represent 95% confidence intervals derived from RMARK (Laake 2013). No estimates are provided for 6- or 8-week post-hatching, to stay consistent with trapped brood analysis.

survival model to account for brood mixing, but the modification did not account for combined broods of >1 female. The Lukacs survival model is well-suited for flush counts where survival is based on the radio-tagged female, but the survival estimate does not accommodate brood mixing because it is a confounding factor in the estimate of detection probability with the changing brood sizes (Lukacs et al. 2004). Use of known-fate models is another option, but known fate models assume 100% detection, which we documented might not be appropriate (White and Burnham 1999). To account for these issues and potential assumption violations in the Lukacs survival model, we excluded flushes whereby >1 female was observed. We thereby satisfied that assumption for the Lukacs model, but brood mixing has been documented to improve survivorship in other avian species (Nastase and Sherry 1997). While the survival benefits of brood flock formation have not been documented in wild turkeys, this suggests that our censoring method may negatively bias *S* (assumption 6, Tsai et al. 1999), assuming brood flocks improve overall poult survival.

To test the effect of trapping and transmitting poults, we had to make a few assumptions related to the use of a known fate model to estimate survival rates of unmarked individuals, after repeated flush counts. First of all, we assumed 100% detection probability, which likely positively biased our survival estimates, since our detection

TABLE 5 Model selection table of flush count data from wild turkey broods in south-middle, Tennessee, USA, during 2018–2022. Week represents the week the flush was conducted and trapped brood vs. non-trapped brood and tagged poults vs. untagged poults represent the dummy variables used to signify whether or not the respective brood was trapped or poult was radio-tagged.

Model	*K*[a]	AIC_c[b]	ΔAIC_c[c]	*wi*[d]	Log likelihood
S(2-week × trapped brood vs. non-trapped brood)	4	1150.38	0	0.95	−571.16
S(Year)	5	1156.18	5.80	0.05	−573.05
S(2-week)	2	1173.75	23.37	0	−584.87
S(2-week × tagged poults vs. non-tagged poults)	4	1175.10	24.72	0	−583.52
S(Trapped brood vs. non-trapped brood)	2	1196.79	46.41	0	−596.39
S(Tagged poults vs. non-tagged poults)	2	1207.05	56.67	0	−601.52
S(.)	1	1207.51	57.13	0	−602.75

[a]Number of parameters.

[b]Akaike information criterion for adjusted sample sizes.

[c]Change in Akaike information criterion for adjusted sample sizes.

[d]Model weight.

probability was <1 ($p = 0.84$) for flush counts. That will introduce some bias into our poult survival estimates that were derived from flush count data with known-fate models, but this bias was introduced across all groups. The formation of brood flocks would bias our estimates positively if the poults of other females were counted as the marked female's poults or negatively if the poults of the marked female were not counted and were considered to belong to another female. By averaging the number of poults, we aimed to mitigate this bias, and it likely affected all broods equally, but a bias likely exists nonetheless.

Trapped poults experienced reduced survival during the first 14-day monitoring period based on the known-fate model (0.22 lower, on average, than non-trapped broods in the first 14-day period). Based on 62 successful trap nights, we estimated a capture mortality rate of 1.6% (4 poults died during or following trapping events). Although direct capture myopathy was low, there may have been additional mortality of non-tagged poults that went undetected. Our trapping method involved flushing the brood in low-light conditions while they were ground roosting (i.e., prior to the poults being able to thermoregulate). During trapping events, we rarely caught all the poults because of their ability to escape in relatively dense vegetation, and any missed poults (i.e., non-tagged poults) could have been exposed to elements or predation while away from the female. The potentially undetected capture-related mortality does not inherently violate the assumption of estimating poult survival because radio-tagged poults are not being impacted, but it does bias survival estimates from flush count data or brood survival estimates.

Our findings support using poult survival estimates as a metric for calculating recruitment, because we did not see drastic changes in poult survival after 28 days post-hatching. The juvenile life stage of wild turkeys, from hatching until the next breeding season, has been unstudied largely because juveniles are difficult to capture and mark until they are old enough to be trapped using conventional methods (i.e., rocket nets) during their first winter (Londe et al. 2023). Although our monitoring period was only 56 days and did not extend all the way to the following nesting season, recruitment or juvenile survival could be approximated based on monitoring the survival rates of the brooding females. Additionally, we demonstrated that it was feasible to continue monitoring broods to day 56 (8 weeks) post-hatching with either method. The average radio-tag battery life of 78 days (range: 38–97 days) was capable of monitoring a 56-day period, consistent with other suture-style radio-tag studies (Burkepile et al. 2002: 56 days, greater sage grouse; Orange et al. 2016: 51–80 days, northern bobwhite).

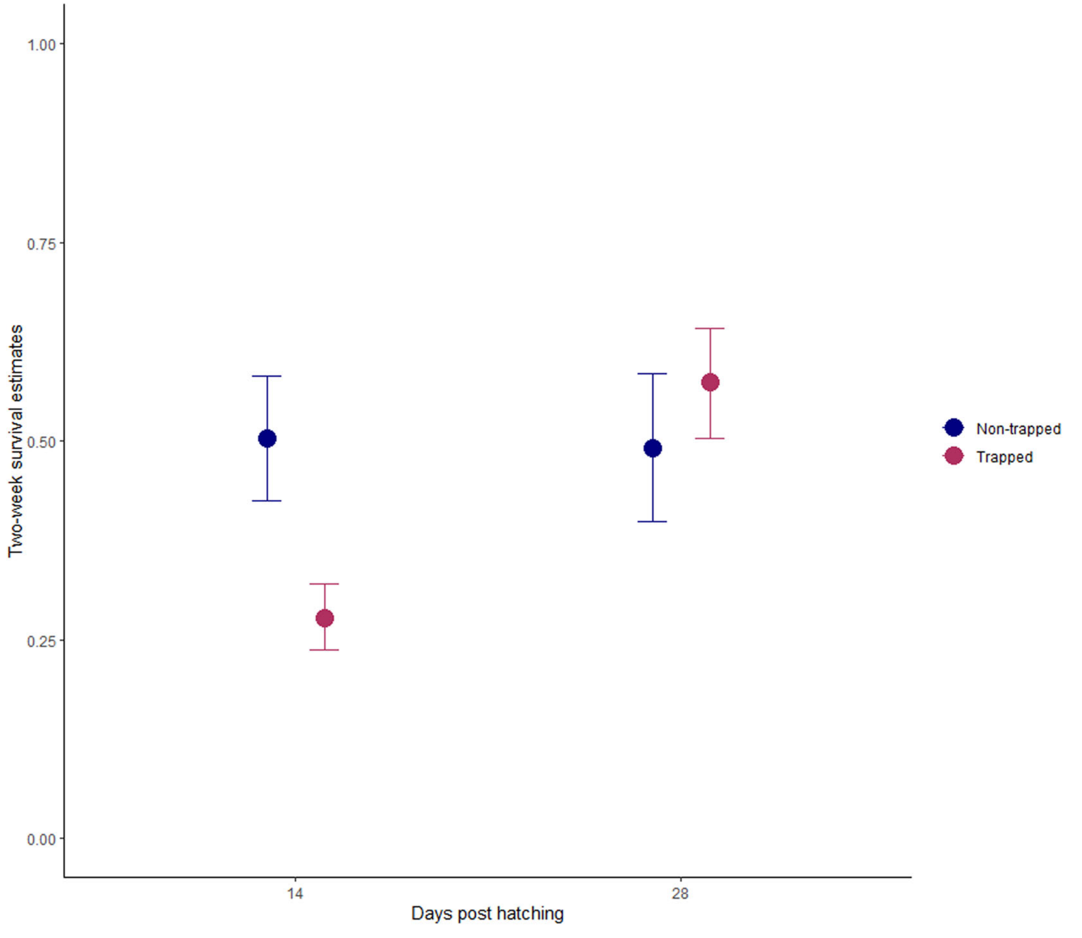

FIGURE 5 Two-week wild turkey poult survival estimates of trapped broods vs. non-trapped broods using flush count data during 2018–2022 in south-central, Tennessee, USA. Error bars represent 95% confidence intervals derived from RMARK (Laake 2013). No estimates are provided for 6- or 8-week post-hatching, because no non-trapped broods were flushed past day 28.

RESEARCH IMPLICATIONS

Radio-tagging and flush count methods produced similar poult survival estimates throughout the 56-day monitoring period, but both methods violated various assumptions, such as dependent survival between brood mates, impacts of trapping, and issues meeting model-specific assumptions. Dependent poult survival among poults within the same brood was documented in both methods. Understanding this underlying effect on the variance should be taken into account when interpreting poult survival estimates. For radio-tagged poult survival estimates, we documented lower survival rates of trapped broods when compared to non-trapped broods in the first 14-d monitoring period, which may bias those estimates low. More research into less invasive trapping methods may be beneficial to help improve trapping methodology and increase the practicality of radio-tagging poults. Known-fate models were well-suited for radio-tagged poult methods, though poults with unknown fates bias estimates, whereas Lukacs survival models dealt with this issue but did not allow for brood flock formation, which limits the number of broods that can be incorporated into the survival model. These considerations should be taken into account when deciding on which sampling method to use for estimating poult survival as well as the research question. Additionally, 56-day brood monitoring periods provided additional insight into the poult survival trends and can help researchers better understand recruitment and juvenile survival in their wild turkey populations.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

All animals were captured and handled with care and the appropriate permits by trained personnel under University of Tennessee IACUC Protocol #0561-0720.

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