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RESEARCH ARTICLE

Survival and movements of brown-headed nuthatches after translocation to the Missouri Ozarks

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Abstract

The brown-headed nuthatch (*Sitta pusilla*) was likely extirpated from Missouri in the early 1900s as a result of habitat loss through extensive logging. Conservation partners including the Missouri Department of Conservation, United States Forest Service, University of Missouri, and others, relocated 102 brown-headed nuthatches from Ouachita National Forest in Arkansas to Mark Twain National Forest in Missouri in 2020 and 2021 to establish a local population. We tracked 50 individuals for 24 ± 11 (median ± SD) days after release using radio telemetry and monitored movements in relation to sex and whether a bird was captured alone or as part of a group. We examined 25-day survival using a spatial Cormack Jolly Seber (sCJS) model to account for likely dispersal outside of our study area. All birds survived capture, transport, and release. The 25-day survival estimate was 0.56 (95% CI = 0.36–0.78) in 2020 and 0.68 (95% CI = 0.46–0.89) in 2021. Mean total distance moved following release was 5,670 (SD = 3,407) m and mean daily movement was 243 (SD = 135) m which was less than the mean daily dispersal distance estimated from our sCJS model (420 m, SD = 221). Our short-term monitoring suggests initial success of the translocation, but continued monitoring is needed to evaluate long-term success. Our survival analysis approach, which included movement data, illustrates the importance of considering dispersal when estimating survival.

KEYWORDS
Bayesian, brown-headed nuthatch, Missouri Ozarks, reintroduction, *Sitta pusilla*, spatial Cormack Jolly Seber, survival, translocation

Translocation is a well-known method to reestablish extirpated species where recolonization is impossible or unlikely (International Union for Conservation of Nature/Species Survival Commission [IUCN/SSC] 2013). Translocations can be used to reestablish historic community composition and function as part of holistic ecosystem restoration (Lipsey and Child 2007). Reestablishing extirpated species that perform key ecological roles may also improve overall ecosystem health (Dobson et al. 2006, Lipsey and Child 2007). Translocations outside a species' established range may also be desirable as a climate adaptation approach. The reintroduction of species associated with restored ecosystems can also help assess the success of restoration (Lipsey and Child 2007, Lloyd et al. 2009). Both short- and long-term monitoring of a reintroduced population is important for assessing the success of a reintroduction and is also critical in guiding future reintroduction efforts (IUCN/SSC 2013).

The brown-headed nuthatch (*Sitta pusilla*) is a pine-woodland obligate songbird that was likely extirpated from Missouri in the early 20th century when >2 million ha of shortleaf pine (*Pinus echinata*) woodland in the Ozark region were removed by extensive logging (Cunningham 2007, Eddleman et al. 2007, Robbins 2020). Logged areas were then converted to other land uses, primarily grazing, or regrew as closed-canopy oak (*Quercus spp*.)-pine (*Pinus spp*.) or oak-hickory (*Carya spp*.) forest (Cunningham 2007). Brown-headed nuthatches excavate nest cavities predominately in pine snags and, as primary cavity excavators, they play an important ecological role for several secondary cavity-nesting species (O'Halloran and Conner 1987, Slater et al. 2021).

Decades-long efforts by the Mark Twain National Forest to restore shortleaf pine and oak woodland in the Ozarks have resulted in a landscape that is believed to support the brown-headed nuthatch. Restoration and management of pine woodland usually consists of tree thinning to reduce canopy cover and remove the midstory and prescribed burning to prevent the redevelopment of a midstory and stimulate ground cover. The Mark Twain National Forest began pine woodland restoration in the early 2000s and accelerated efforts in 2012 with support from the Collaborative Forest Landscape Restoration Program, which coordinated efforts by state, federal, and nongovernmental organization partners to restore shortleaf pine woodland in the state. As a result, 24,129 ha of Mark Twain National Forest and surrounding areas have been restored to shortleaf pine-oak woodland (B. K. Davidson, U.S. Forest Service Mark Twain National Forest, unpublished data). A habitat suitability analysis suggested the area could likely support a population of ~1,400 brown-headed nuthatches (T. W. Bonnot, U.S. Fish and Wildlife Service, unpublished data). Furthermore, restored pine woodland may be more resilient to climate change than the closed canopy oak-pine forest that had replaced it (Stambaugh and Guyette 2004, Prasad et al. 2007, Jin et al. 2018). Accordingly, reintroducing brown-headed nuthatches was desirable to conservation partners from both ecosystem restoration and climate change adaptation standpoints.

Successful translocations of brown-headed nuthatches have taken place elsewhere in recent decades. A translocation of brown-headed nuthatches in southern Florida moved 47 birds over 4 years using a soft-release method with outdoor aviaries and supplemented food and water for 1- to 7-days prior to release. Post-release monitoring was conducted using line transects and conspecific playback twice per year for 5 years post release and indicated population persistence (Lloyd et al. 2009). Lloyd et al. (2009) primarily translocated entire family groups, which can include up to 6 or more individuals prior to juvenile dispersal, presumably to increase survival and breeding success, because brown-headed nuthatches are cooperative breeders

(Slater et al. 2021). A second reintroduction effort in south Florida did not target family groups, but instead focused on capturing juvenile nuthatches during a period in the annual cycle when juveniles typically disperse (Cox et al. 2022*b*). Due to funding constraints, monitoring efforts for both reintroductions were limited to recurring counts and attempts to resight color-marked individuals within released areas (Lloyd et al. 2009, Cox et al. 2022*b*, J. A. Cox, Tall Timbers Research Station, personal communication). Neither study incorporated radio telemetry to monitor movements and survival.

Radio telemetry is commonly used to monitor movements and survival in avian studies, but constraints exist when using this method on small passerines. First, mortality events are rarely captured. The lightest avian radio-tag capable of a programmed mortality signal weighs 6 and 8 g (Advanced Telemetry Systems© and Lotek©, respectively; Advanced Telemetry Systems, Inc., Isanti, MN, USA and Lotek Wireless Inc., Newmarket, Ontario, Canada) and can be used only on large (>150 g) birds (e.g., bobwhite quail, *Colinus virginianus*, Wann et al. 2020). Thus, known-fate survival models, which are common in telemetry studies, are difficult to apply to brown-headed nuthatches given weight limitations of transmitters (Barron et al. 2010). Second, small radio tags have a short detection radius that increases the likelihood that a tagged individual will not be detected and subsequently not included in survival analyses if it emigrates ≥500 m outside a search area. Capture-recapture survival models with a state-space component have been used to account for dispersal from a study area in resighting studies of small songbirds (Schaub and Royle 2014, Reidy et al. 2018). Combined with radio telemetry, this modeling approach accounts for uncertain fates and emigration that are likely to be high in a reintroduced population of small passerines such as this case.

Our objective was to evaluate the effectiveness of our translocation methods for brown-headed nuthatches to inform similar reintroduction efforts by describing capture, transportation, release, and monitoring methods and reporting movements and survival for the 25 days following release. We analyzed radio telemetry data to estimate post-release movements and survival and if movement behavior and survival varied with year of release, sex, or if individuals were part of a putative family group (family group or neighbors captured in the same net). In doing so, our focus was to understand the effects of sex ratio, group captures, and annual variation on posttranslocation dispersal of brown-headed nuthatches for future translocation efforts.

STUDY AREA

We captured brown-headed nuthatches in the Poteau-Cold Springs District of the Ouachita National Forest (1,350 km^2 unit) in western Arkansas (Figure 1). The Ouachita National Forest covers >11,000 km^2 of the Ouachita Mountains ecoregion and consists primarily of oak-hickory-pine and loblolly (*Pinus taeda*) and shortleaf pine cover types with some grassy woodlands (Arkansas Department of Agriculture 2020). We concentrated captures along accessible roads and areas dominated by shortleaf and loblolly pines.

We released brown-headed nuthatches in restored shortleaf-pine woodlands in the Eleven Point Ranger District of Mark Twain National Forest in the Ozark Highlands ecoregion of Missouri (Figure 1). The region consists of large, contiguous tracts of oak–hickory and oak–hickory–pine forest, restored shortleaf pine-oak woodland, bluestem (*Andropogon gerardii* and *Schizachyrium scoparium*) prairie, and eastern redcedar (*Juniperus virginiana*) glades (McNab and Avers 1994). The elevation ranges from 112 to 386 m with rolling to rugged terrain and karst landscapes with exposed rock, caves, and spring systems (Missouri Department of Natural Resources 2016). Climate consists of hot, humid summers and cool relatively dry winters; 30-year average annual precipitation was 122.8 cm and mean monthly temperatures range from 0.9°C in January to 25.5°C in August (PRISM Climate Group 2023). Natural recolonization of brown-headed nuthatches to restored habitat in the region was unlikely because they are sedentary and extensive barriers to dispersal now exist between Mark Twain National Forest and the closest extant population in Arkansas (>100 km away; Haas et al. 2010, Bonnot et al. 2019).

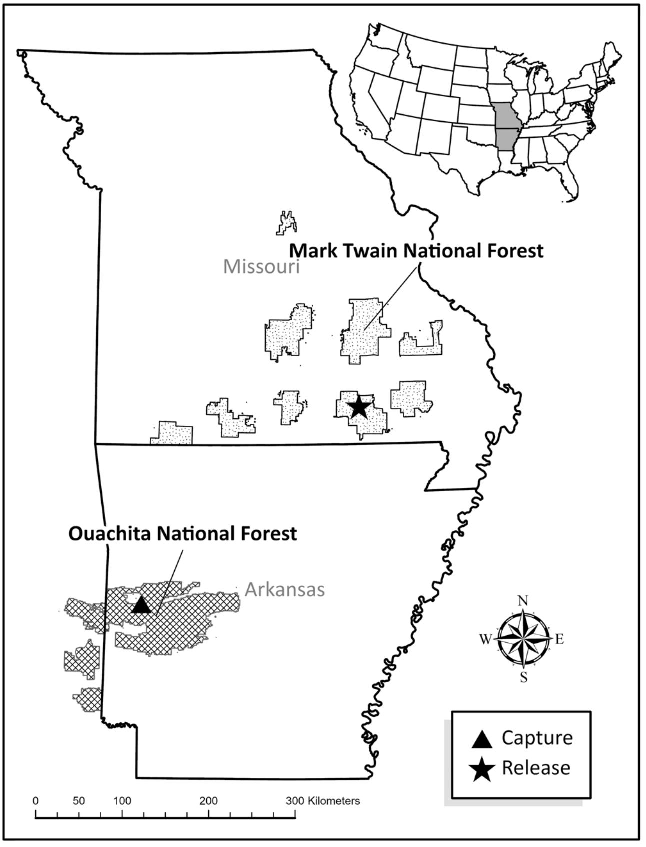

FIGURE 1 Brown-headed nuthatch (*Sitta pusilla*) capture site at Ouachita National Forest in Arkansas, USA, and release site at Mark Twain National Forest in Missouri, USA, during translocation events in 2020 and 2021.

METHODS

Capture

We captured brown-headed nuthatches from 24 August to 25 September in 2020 and 23 to 29 August in 2021. We spread captures over 4 weeks in 2020 due to inclement weather. We captured individuals during the post breeding phase when aggressive territorial interactions are less common and to provide translocated birds with time to explore novel habitats and locate potential winter roost sites (cavities in snags), which are likely to be important for brown-headed nuthatches (J. A. Cox, Tall Timbers Research Station, unpublished data) and the congeneric pygmy nuthatch (*Sitta pygmaea*; Sydeman and Güntert 1983). Capturing nuthatches in the post breeding phase also provided individuals time to socialize, establish territories, pair, and excavate nest cavities in the following breeding season.

We spread capture sites across a large area (>300 km^2) to promote genetic variation among captured birds in a reintroduced population (Haas et al. 2010). Our capture efforts consisted of road-based scouting of trapping sites the day prior, site preparation and setup of elevated mist nets, and early morning target netting with conspecific playbacks that included male and female vocalizations (Cox et al. 2022*a*). We scouted potential sites along roadsides using conspecific playback and marked areas where nuthatches responded to playback. We set up mist nets at trapping locations the day before or the morning of captures. We placed nets close to low branches of pines

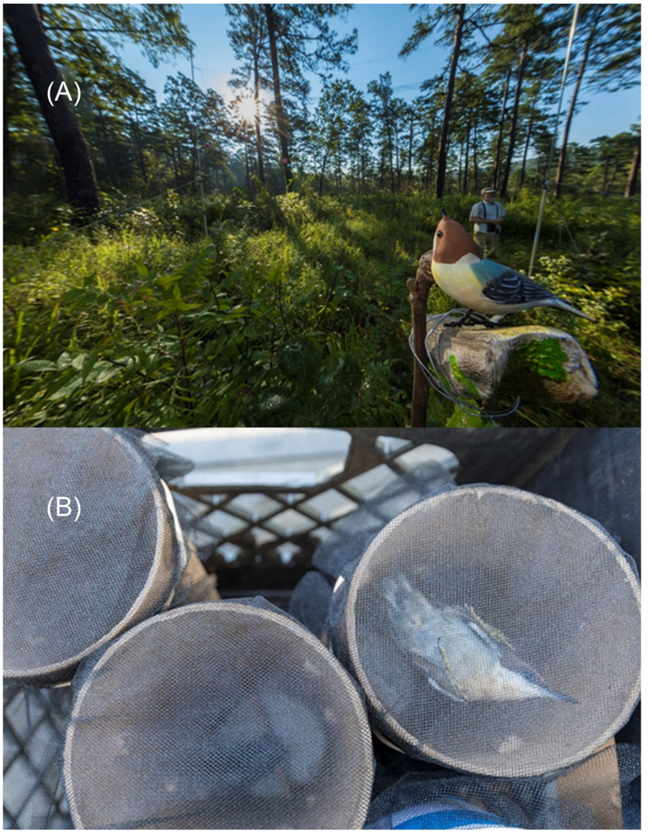

FIGURE 2 A decoy (A) used to lure brown-headed nuthatches (*Sitta pusilla*) into elevated mist-nets in Ouachiata National Forest, Arkansas, USA for translocation to Ozark National Forest, Missouri, USA. Brown-headed nuthatches were transported in cardboard mailing tubes with a dowel rod perch (B).

or near short snags where nuthatches often perch when responding to the conspecific playbacks to increase likelihood of capture. We used 6- and 9-m mist nets on 2, 3-m conduit poles secured to extendable painters' poles using d-ring trailer pins through predrilled holes. The extendable poles enabled us to elevate mist nets to the lower branches of mature trees where brown-headed nuthatches often perch when responding to playbacks. We placed speakers in small saplings or snags near the net or on the ground below the net to encourage nuthatches to move closer to our nets. We also placed decoys of brown-headed nuthatches on a neighboring sapling, tree, snag, or net pole to elicit territorial responses near nets (Figure 2). We opened mist-nets between 06:30 and 07:00. If nuthatches responded to playback, we left the nets open for ≤15 minutes. If no nuthatches responded, we lowered nets and moved them to other locations. We continued this process until 08:30 in 2020 and until 09:30 in 2021. We did not conduct captures if it was raining at the capture site or there was rain or fog at either of the regional airports that prevented plane flights for transporting birds.

Translocation

We extracted captured brown-headed nuthatches from mist-nets and placed each bird into 10- by 25-cm cardboard mailing tubes with a 6.35 mm dowel rod for a perch in the bottom (Figure 2). We secured the top with at least 2 layers of black tulle fabric and a thick rubber band. We placed 5 live mealworms in the tube after capture.

We transported tubes in milk crates covered with dark cotton fabric to reduce noise and light reaching captured birds. We combined and transported each day's captures to a local airport within one hour's drive. We then loaded crates into the cabin of a small aircraft where they were flown to southern Missouri. Flight time was approximately 80–90 minutes depending on weather and the type of aircraft used. Crates were shuttled 45 minutes from the airport to the release site in Mark Twain National Forest. In total, translocation time from capture to release ranged from 4 to 6 hours.

Release

We released brown-headed nuthatches at a single site in 2020. In 2021 we split releases in half between 2 sites (one was the 2020 release site) to facilitate dispersal farther into areas of suitable habitat (Figure 3). We released

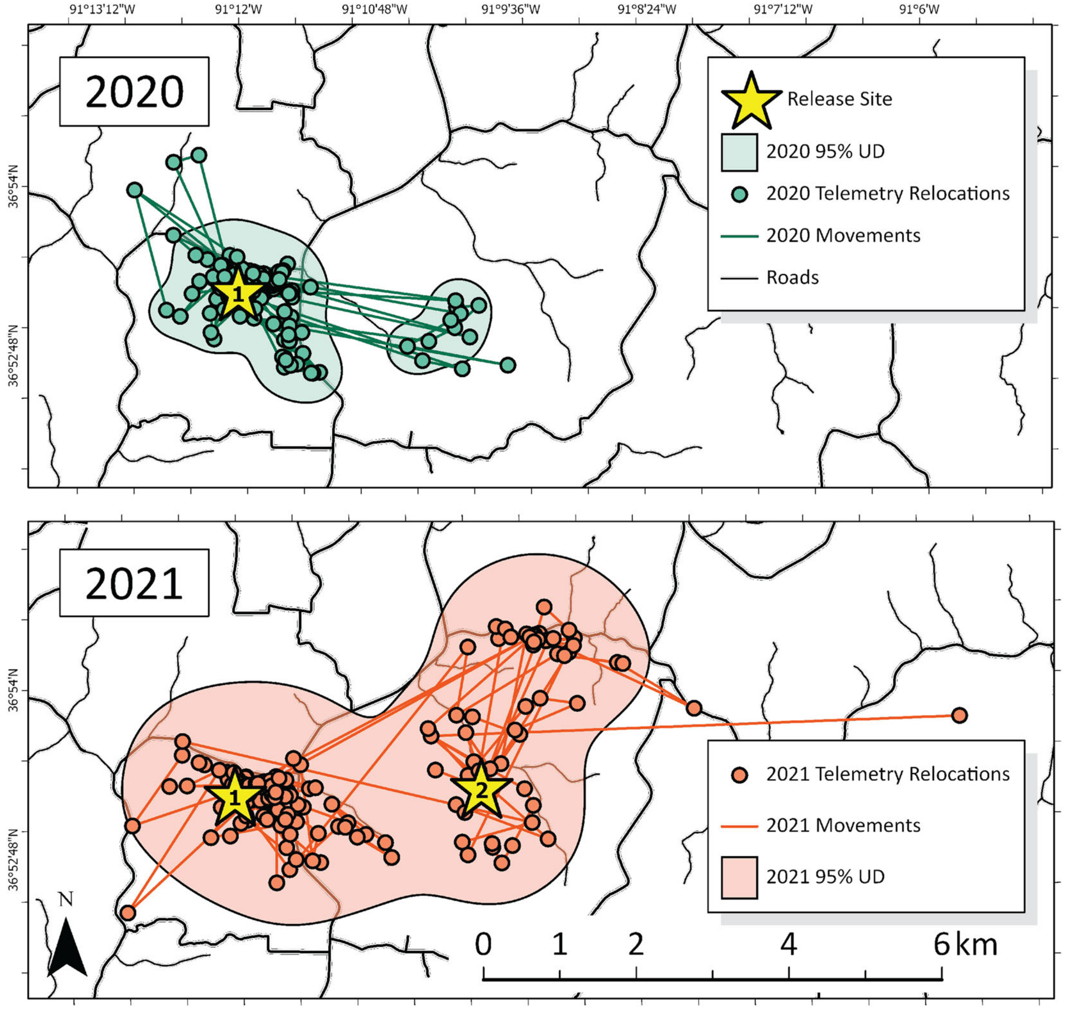

FIGURE 3 Relocations, movements, and 95% utilization distributions (95% UD) of tagged and reintroduced brown-headed nuthatches (*Sitta pusilla*) at one release site in 2020 (star labeled 1) and 2 release sites in 2021 (stars labeled 1 and 2) in Mark Twain National Forest, Missouri, USA.

birds between 12:00 and 14:00. At the release sites, we banded each brown-headed nuthatch using a USGS federal aluminum band (size 0) and 1 or 2 Darvic color bands (size 2.8–3.0 mm) on the opposite leg. We did not put color bands on the same leg as the aluminum bands, and shortened color bands by ~2 mm each, because abrasion and leg injuries can occur if 2 factory-provided color bands are used (J. A. Cox, Tall Timbers Research Station, unpublished data). We used a razor knife or a Dremel© rotary tool (Robert Bosch Tool Corporation, Gerlingen-Schillerhöhe, Germany) to shorten color bands. Color-band combinations were unique to each individual. We aged all birds as hatch-year or after-hatch-year by examining molt-limits or skull ossification (Pyle 1997) in 2021. We pulled approximately 5 ventral feathers and sent these to Animal Genetics (Tallahassee, FL, USA) for genetic sexing (Ellergren 1996).

We attached Lotek PicoPip Ag337 VHF radio transmitters (Lotek Wireless Inc., Newmarket, Ontario, Canada) to half of the individuals translocated each year. We apportioned transmitters to half of the nuthatches being released per day and avoided attaching transmitters to individuals captured in groups at the same net. We attached transmitters in 2020 using black, ultrathin elastic cord (Sew-ology©, Fabric Editions, Inc., Greenville, SC, USA) and a leg-loop harness method (Streby et al. 2015). We used the smoother and slightly smaller Stretch Magic© cord (0.5 mm diameter, Soft Flex Company, LLC., Sonoma, CA, USA) in 2021 to further minimize harness weight. Total weight of transmitter and harness was ~0.30 g, which was ~3% of a brown-headed nuthatches' body mass. We glued an 18 cm section of harness material to the top of each transmitter before the banding day. To attach the harness, one bander held the bird while another bander guided the harness material around its legs and glued the harness material to the transmitter using Loctite© Super Glue, Ultra Liquid Control (Henkel Corporation, Westlake, OH, USA). We also applied a drop of Starbond© Accelerator (CPH International LLC, Torrance, CA, USA) to dry the glue rapidly. Full drying of the harness was <10 seconds. Once we cut the excess harness material, we trimmed the antenna to 1 cm longer than the tail. We weighed all nuthatches immediately before release. Processing time for an untagged bird was 2 minutes; processing time for a tagged bird was 5 to 6 minutes.

Post-release monitoring

We attempted to locate all tagged birds at least twice a week to monitor nuthatch survival and track post-release movements. We used Advanced Telemetry Systems© R410 handheld receivers (Advanced Telemetry Systems, Inc., Isanti, MN, USA) and a 3-element Yagi antenna. We also used a 5-element Yagi antenna mounted to a truck cab to scan for radio-tagged birds from roads. We scanned roads around known suitable habitat (i.e., open canopy, pine-oak woodland) near the release site and surrounding pine-oak woodland within 3–6 km of the release site. We homed in on birds on foot and confirmed their status and recorded their locations (±5 m) with a Garmin eTrex20 GPS device (Garmin, Ltd., Olathe, KS, USA). We also conducted 3 radio-tracking searches of ~160 km^2 around the release sites from a helicopter with a 5-element Yagi antenna mounted to the front on 5 October 2020, and 8–9 September 2021 (Figure 4). Each search was ~2 hours long at 30- to 60-m altitude. The purpose of the searches was to find missing birds that we could not locate in our regular search grid. We searched for tagged birds that had already been located on foot to test the detectability of radio-tagged birds from the helicopter. We were able to detect radio-tagged birds from the helicopter 0.5–1.0 km away.

Movement analysis

All analyses were conducted in program R (R Core Team 2022, version 4.2.3). We defined a movement as the Euclidean line between 2, temporally-consecutive relocation points recorded for an individual. We calculated movement distance with the step_length function in the amt package and calculated the mean by dividing total

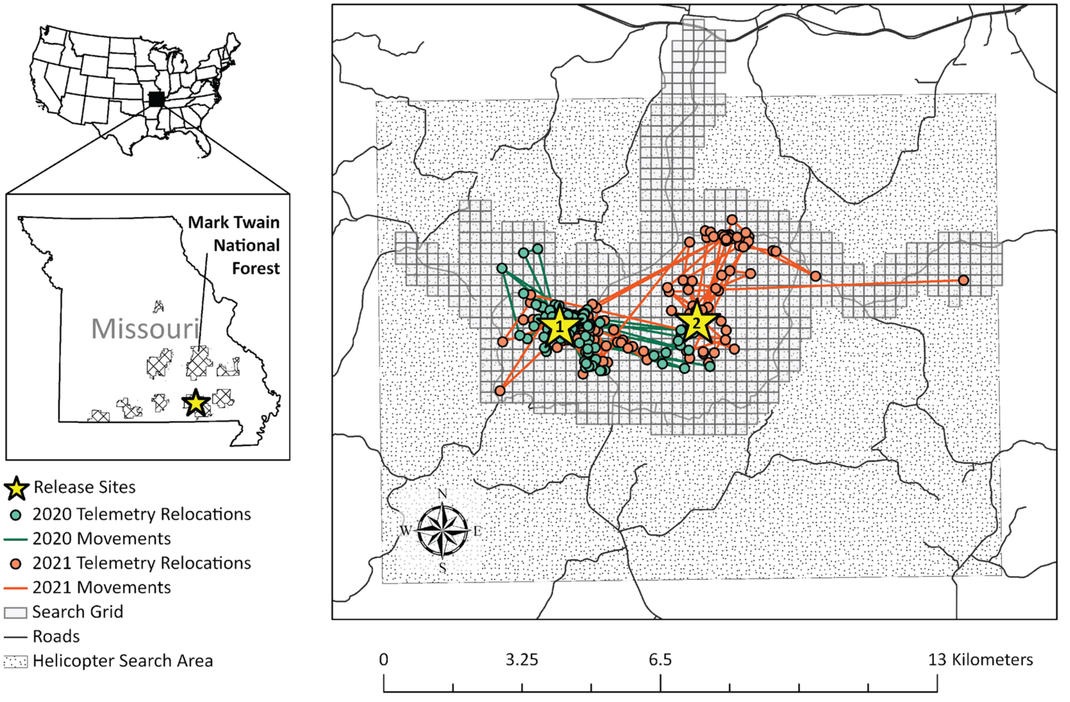

FIGURE 4 Radiotracking of reintroduced brown-headed nuthatches (*Sitta pusilla*) in the Missouri Ozarks in 2020 and 2021. We released birds at one location in 2020 (star 1) and 2 locations in 2021 (star 1 and 2). The search grid overlays areas and roads searched regularly using 3 and 5 element Yagi antennas. The helicopter search polygon encompasses ~95% of the area flown over during 3 flights, 1 in 2020 and 2 in 2021.

movement distance by the number of elapsed days the individual was tracked (Signer et al. 2019). We calculated mean daily movement for each individual and reported the mean and standard deviation (SD) of mean daily movements for our sample of individuals. We defined mean, exploratory home-range size of an individual as the 95% volume of fixed kernel utilization distribution (UD) using all relocations (package adehabitatHR, Calenge 2006). However, home range analyses require ≥5 relocations (Calenge 2006), which precluded some of our tagged birds from analysis. We defined max displacement as the farthest distance a bird was relocated from its original release site. We used linear regression to determine effects of sex and individuals captured in groups or alone (to account for potential effects from social relationships) on mean daily movement, max displacement, total movement distance, and exploratory home range size (lm function, R Core Team 2022, version 4.2.3). We assumed that a bird caught in the same net was a family member for the purpose of our analyses, but birds from adjacent territories may also have been caught in the same net; we believe this likelihood was negligible, however. We did not compare adults to hatch-year birds in our analyses due to insufficient data in 2020 (Table 1). We included all data in our movement analyses, including those movements >25 days post-release.

Survival analysis

We expected dispersal to be high immediately after release, so we modeled survival using a spatial approach that integrated movement data to account for potential dispersal of individuals outside the area we monitored. We

TABLE 1 Sex and age of radio-tagged brown-headed nuthatches (*Sitta pusilla*) reintroduced to the Missouri Ozarks, Missouri, USA, in 2020 and 2021.

	Female				Male				Unknown		
Year	AHY[a]	HY[b]	U[c]	Total	AHY	HY	U	Total	AHY	Total	Grand total
2020	4	5	-	9	5	3	7	15	-	-	24
2021	6	4	-	10	11	4	-	15	1	1	26

[a]After-hatch-year; adults, or birds older than one year.

[b]Hatch-year; juveniles, or birds younger than one year.

[c]Unknown-age birds.

estimated a 25-day period survival because transmitters were expected to last 26 days. We estimated survival of radio-tagged brown-headed nuthatches with a spatial Cormack Jolly Seber mark-resight model (sCJS). The sCJS model uses spatial location data to model the fraction of dispersal that occurs within the study area and can help estimate dispersal outside of the area (Schaub and Royle 2014). A hierarchical model combines the 2 state processes (i.e., survival and dispersal) with an observation process that accounts for imperfect detection. The second state process model describes the dispersal locations G as a random walk where the next location $G_{i,t+1}$ for an individual i at time t + 1 is normally distributed with a mean centered on the current location $G_{i,t}$ and a variance that is estimated by

$$G_{i,t+1}, \sim \text{Normal}\left(G_{i,t}, \sigma_G^2 I\right),$$

where σ_G^2 are dispersal variances in *x*- and *y*-directions (Schaub and Royle 2014). We generated a 250 m grid of our search area and overlaid all habitat that was searched daily to delineate the study area. We also included a 500 m buffer around all regularly searched roads which reflects a reasonable maximum distance that we could hear a radio signal from a tagged bird with relatively clear line of sight across terrain and vegetation (Figure 4).

We initially compared 2 *a priori* survival models, each with year-specific survival ($\phi^{[YEAR]}$) and year-specific encounter rate ($p^{[YEAR]}$) to examine differences in ϕ and p between release years. The first model nested sex within year for ϕ and p and the second, family in year for ϕ and p. We compared the expected log pointwise predictive density (elpd; package loo, Vehtari et al. 2020) between models and because the difference was <0.10, which indicated neither model was better supported (Vehtari et al. 2017), we chose the base model with only year-specific ϕ and p. We examined if modeling family-dependent variance in the dispersal parameters ($\sigma^{[FAM]}$) better estimated survival because movement analyses suggested that daily movements differed between individuals and birds in family groups. However, elpd did not indicate stronger support for the model with $\sigma^{[FAM]}$ so we selected the more parsimonious model with only year-dependent ϕ and p.

We fit models using program JAGS (v. 4.3.0, Plummer 2003) called from program R (package jagsUI, Kellner 2021). We used the Markov chain Monte Carlo method for all models (chains = 3, iterations = 12,000, and burn-in = 500) and we used vague priors for all parameters. We chose a uniform (0, 1) prior distribution for both ϕ and p and a uniform (0, 500) distribution for σ. We assessed the convergence of each parameter by visually inspecting posterior densities and using the Gelman-Rubin statistic, $\hat{R}$, where $\hat{R}$ < 1.01 indicated model convergence (Gelman and Rubin 1992). We assessed model goodness of fit using a posterior predictive check (Kéry and Schaub 2012). We plotted dispersal probability by distance and calculated the model-estimated dispersal distance from calculations specified in Schaub and Royle (2014) using posterior samples of σ_G^2 in both x and y dimensions. We report the mean and 95% credible interval of the posterior distribution for model parameters and estimates.

RESULTS

We captured 18 females, 27 males, and 1 brown-headed nuthatch of unknown sex (i.e., genetic sexing was inconclusive) in 2020. We captured 20 females, 33 males, and 3 birds of unknown sex in 2021. We captured nuthatches at >40 separate trapping locations in Ouachita National Forest spaced ≥200 m apart. We trapped 28 birds without a group member (captured alone in a net) and 74 birds with at least one group member (28 groups of 2–5 birds). Mean number of days tracked was 25 days (SD = 7). We attached VHF transmitters to 24 brown-headed nuthatches in 2020 and 26 in 2021 (Table 1). Over both years we collected 365 locations of radio-tagged birds during VHF telemetry tracking periods. However, our tracking effort differed between years primarily due to weather; on average, we were unable to track 13 out of 25 days in 2020 compared to 4 days in 2021. We did not confirm any mortalities during tracking periods in either year. However, we found evidence of 2 dropped tags in 2020 and 3 dropped tags in 2021; one of these dropped tags in 2020 was due to a loose harness and was found 1 day after release. Further, 7 birds were not relocated >5 days after release (2 in 2020 and 5 in 2021; 2 of these birds were resighted in 2022, 278–518 days after their release, one without a transmitter) and one tagged bird was relocated only once 27 days later. We obtained ≥3 locations and estimated daily movement for 37 of 50 radio-tagged birds, which we tracked up to 45-days post release. We relocated radio-tagged birds on average 10 ± 4 times (n = 37 individuals). Our movement analyses included 37 birds which were relocated >2 times, >5 days after release, and did not drop their transmitter.

Mean daily movement was 244 m (SD = 135, min–max = 47–662, n = 37), mean total was 5,821 m (SD = 3,321, min–max = 1,164–16,210, n = 37), and mean maximum displacement from the release site was 1,562 m (SD = 1,025, min–max = 118–6,326, n = 37). Mean exploratory home range size was 819 ha (SD = 1,203, min–max = 8–6,210, n = 34). Tagged males had similar mean daily movement as tagged females (β = 6.983, $t_{2,34}$ = 0.150, P = 0.882; Figure 5). Also, tagged males had similar total movement distance (β = 449.600, $t_{2,34}$ = 0.396, P = 0.694), home range size (β = −41.280, $t_{2,31}$ = −0.095, P = 0.925), and max displacement (β = 233.300, $t_{2,34}$ = 0.667, P = 0.509) as females. Birds caught in a group had similar total movement distance (β = 1,209.000, $t_{1,32}$ = 1.231, P = 0.227) and home range area (β = 619.800, $t_{1,32}$ = 1.410, P = 0.169) as birds captured alone (Figure 5). However, birds captured with a group had a higher max displacement than those captured alone (β = 790.600, $t_{1,32}$ = 2.147, P = 0.0395) and a higher mean daily movement (β = 90.420, $t_{1,32}$ = 2.017, P = 0.0521).

We estimated survival using relocations within 25 days of bird release because transmitters were expected to last at least 26 days. There were 21 relocations of 8 birds in 2020 (14% of 2020 relocations) and 19 relocations of 13 birds in 2021 (10% of 2021 relocations) that occurred after 25 days; these individuals were right censored at 25 days. We detected active transmitters after day 25 for 25% and 50% of birds in 2020 and 2021, respectively. The Bayesian P value of our posterior predictive check was 0.48, which indicated our final model was a good fit for the data. Survival (ϕ) was 0.56 (95% CI = 0.36–0.78) in 2020 and 0.68 (95% CI = 0.46–0.89) in 2021 (Figure 6). Estimates of encounter rate (p) indicated only moderate ability to detect radio-tagged birds in 2020 (0.66, 95% CRI = 0.59–0.73) and even lower detection in 2021 (0.34, 95% CRI = 0.29–0.39). The posterior estimates for the longitudinal and latitudinal components of the dispersal parameter σ were 455.55 (95% CI = 418.09–492.58) and 384.38 (95% CI = 351.80–421.35), respectively, which represented a mean daily dispersal distance of 420 m (SD = 221; Figure 7).

DISCUSSION

Brown-headed nuthatches tolerated the translocation and tagging methods well, with no apparent signs of distress, stress, or changes in behavior during trapping, transport, processing, or tracking for weeks after release. No known mortalities occurred in our handling and radio-tracking of the translocated birds in either year, however, survival estimates suggest some birds either died or our model was unable to completely account for dispersal.

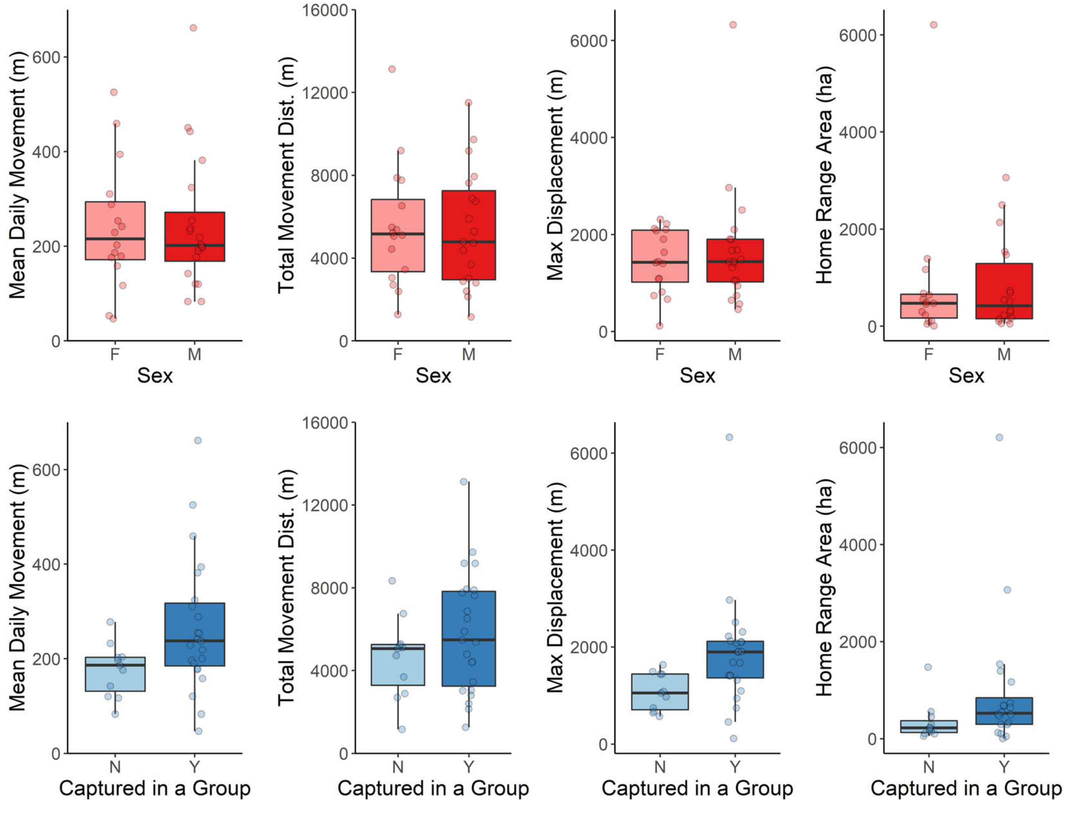

FIGURE 5 Mean daily movement (m; *n* = 37), total movement distance (m; *n* = 37), maximum displacement (m; *n* = 37), and home range area (ha; *n* = 34) of translocated and tagged brown-headed nuthatches (*Sitta pusilla*) in the Missouri Ozarks, Missouri, USA in 2020 and 2021 at 25-days posttranslocation. Each variable is compared by sex (top row, Female = F, Male = M) and whether a nuthatch was captured in a group or alone (bottom row, Yes = Y, No = N). Points are raw values. Boxplots show upper/lower quartiles (top/bottom of box), median (middle line), and max/min (upper/lower whisker lines).

The radio-tagged birds that we re-located dispersed ≤6 km from release sites and were found often in conspecific social groups for months post release outside of the breeding season (March–June). Surveys across the release area have been conducted monthly since November 2020 and nests have been located and monitored spring 2021, 2022, and 2023 (K. M. Heath-Acre, Missouri Department of Conservation, personal observation).

Brown-headed nuthatches that were never seen again after release either dispersed beyond our search areas, died, or had transmitters that failed. Mortality seems less likely given a lack of mortality of the radio-tagged birds for 25+ days post-release. Brown-headed nuthatches are robust resident birds and we captured them in the post-breeding season ~300 km southwest of the release site in a very similar shortleaf-pine woodland ecosystem and climate. Further, we released them in mild temperatures (without notable excessively hot temperatures in 2020 or 2021) and they showed no signs of stress during trapping, transport, or release. Survival estimates may be as low as the survival model reflects, but if mortality was driving this within our search areas, we should have recovered active radio tags from dead individuals as we did in the cases of dropped active tags. This disconnect between low survival estimates and a lack of recovered tags from dead individuals may be due to a high rate of emigration not captured by our model. Further, a high rate of emigration may also explain the high dispersal variance and estimated dispersal of our survival model compared to relatively short average daily movements captured by telemetry tracking. Survival for the 25-day period in our study was lower than survival for the annual periods reported by

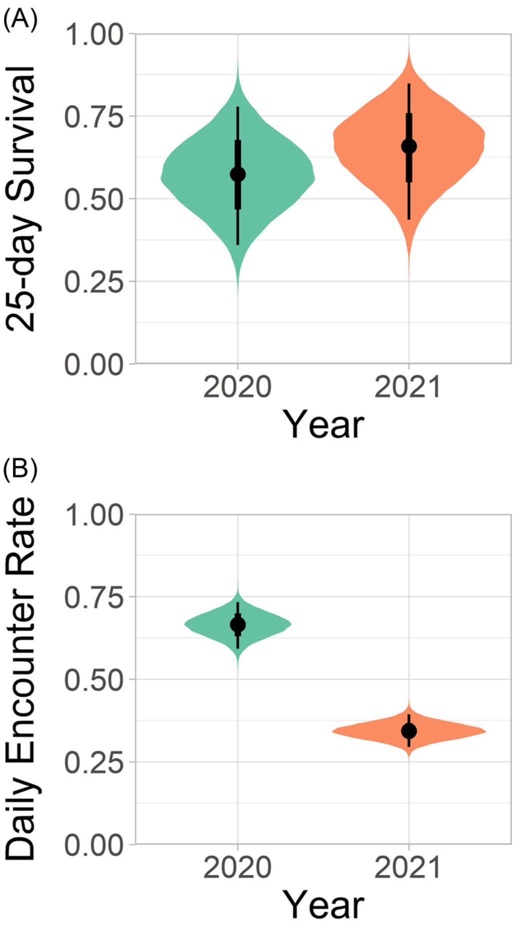

FIGURE 6 Posterior distributions of 25-day survival estimates (A) and daily encounter rate estimates (B) of tagged brown-headed nuthatches (*Sitta pusilla*) reintroduced to the Missouri Ozarks, Missouri, USA, 2020 and 2021. Estimates were created using a spatial Cormack Jolly Seber model in a Bayesian framework, where survival and encounter rate were year-dependent. The embedded eye-plots show the median (black dot), the 66% Credible Interval (thick line), and the 95% Credible Interval (thin line).

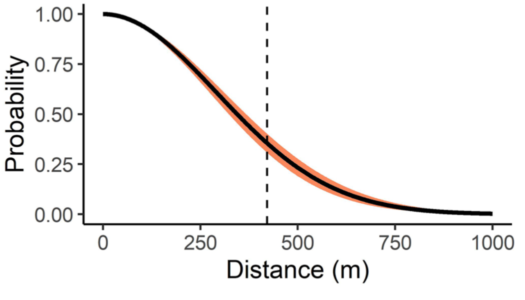

FIGURE 7 Daily dispersal probability distribution of reintroduced brown-headed nuthatches (*Sitta pusilla*) in the Missouri Ozarks, Missouri, USA, in 2020 and 2021. Probability of dispersal was calculated using the dispersal variance posterior distribution from a spatial Cormack Jolly Seber which modeled year-dependent survival and encounter rate. Dispersal mean, 420 m, is indicated by the dotted line.

Lloyd et al. (2009) for translocated brown-headed nuthatches in Florida (0.63, 95% Confidence Interval = 0.55–0.71). However, it seems reasonable that survival would be lower, and dispersal greater, for the 25 days immediately following release than for 5 years post release reported by Lloyd et al. (2009) due to the stress of translocation and introduction into novel habitat (Dickens et al. 2010). Ongoing monitoring and longer-term survival estimates based on resighting color-marked birds will better reflect population persistence and the long-term success of the reintroduction effort.

As we predicted, dispersal played a large role in our survival results. Exploratory home range size in our study was considerably larger than the home range size of resident nuthatches in Arkansas where our translocated birds were moved from (0.3–47.6 ha; Stanton et al. 2014) and was more similar to a population of reintroduced nuthatches in Florida (11.8–267.5 ha; J. A. Cox, unpublished data). The mean daily movement we detected using radio telemetry was nearly half of the mean daily distance moved based on our sCJS model results. Radio-tagged birds moved 100–6,000 m from their release sites, and some likely left our search area at least once or entirely. Our application of the sCJS model to radio telemetry data allowed us to estimate dispersal variance and incorporate this into a survival estimate, and to our knowledge, is unique. Other studies have used a combination of radio telemetry and mark-resight data (Powell et al. 2000, Sollmann et al. 2013). Specifically, Sollmann et al. (2013) used a sCJS model in a Bayesian framework to examine raccoon (*Procyon lotor*) survival and abundance. However, unlike our study, they used radio telemetry relocation data to estimate dispersal variance and mark-resight data to estimate encounter history. Powell et al. (2000) similarly used radio telemetry data to estimate movement rates to better inform survival estimates using traditional mark-recapture methods in a multistate survival model.

Schaub and Royle (2014) suggested the main advantage of the sCJS model is obtaining estimates of survival and dispersal, even in an irregularly shaped study area such as ours. However, Schaub and Royle (2014) warned that if dispersal movements are large with respect to the study area and capture probability is low, estimates of dispersal variance, encounter probability, and survival may all be positively biased. We believe our approach addressed this, and other problems specifically related to monitoring survival of reintroduced populations. First, by using radio telemetry, we were able to capture some long dispersal events by radio tagged individuals that we otherwise would have missed, hopefully mitigating positive bias in our estimates. Second, we were able to establish what portions of the novel habitat were being used, something we could only predict prior to release. Overall, we believe the method is well suited to reintroductions. Dispersal is likely going to be high in a reintroduced population and our approach accounted for it as precisely as possible by using radio telemetry to track movements.

We believe our radio-tag attachment had minimal effects on survival or behavior, which is similarly assumed in other studies of songbirds using comparable transmitter and attachment methods (Gow et al. 2011, Streby et al. 2013). Barron et al. (2010) showed there can be a negative effect of radio tags on survival and breeding behavior of birds. However, studies by Barron et al. (2010) included different species and different attachment methods (Barron et al. 2010). If a negative effect on survival existed in our study, then overall survival of all 102 birds was likely higher than we report here. We suggest radio-tracking a portion of future released populations of small songbirds, where appropriate, to adequately monitor survival post release. However, caution should be taken to balance the benefits of monitoring with the potential negative effects of radio tags on individuals in a population that is establishing in novel habitat, and to maximize its survival and productivity for persistence. Using a glue-on method, rather than a harness, or introducing a weak-link to the harness might better ensure that transmitters don't stay on longer than necessary.

Landscape heterogeneity at our release sites likely affected our ability to find tagged birds at large distances. The landscape surrounding release sites was hilly and composed of extensive areas of oak and pine forest interspersed with tracts of woodland managed with prescribed burning and thinning. More than 90% of the search area is publicly owned, however, small, privately owned plots of land were common and created barriers to tracking. The patchwork of forest and woodland likely affected our ability to detect dispersal movements in every direction and may explain why we did not detect some tagged birds after release. For example, searches were focused on roads near the release-site and in open pine woodland that we could adequately scan, largely due to a limited number of staff. Therefore, if a radio-tagged bird occupied pine forest, or a patch of pine woodland >6 km from either release site, we were not likely to detect it. The first Florida reintroduction translocated 47 birds over 4 years and 21 of those birds were never seen again or only seen once after release (Lloyd et al. 2009). We attempted to document early release outcomes more precisely using radio telemetry and by searching for birds using a helicopter on one day in 2020, at 24 days post-release, and 2 days in 2021, at 10 days post release. While we were able to relocate known birds in our general search area, we did not find any of our missing birds. As part of our subsequent ongoing monitoring efforts, we have resighted 5 birds within 2 km of the release sites that had not been seen for 228–513 days, 2 of which had a transmitter and disappeared during radiotracking in this study (K. M. Heath-Acre, personal communication). Thus, there is evidence that we missed some long-term movements and at least some birds that disappeared during radiotracking were alive and our survival estimates are biased low, although their transmitters may have simply failed. Future efforts might consider the use of passive monitoring such as automated telemetry or audio recording units to track birds inside and around the perimeter of a predefined study area.

Unlike Lloyd et al. (2009), we translocated all brown-headed nuthatches we trapped rather than individuals captured in groups. We found brown-headed nuthatches captured with others in the same net dispersed farther and made larger average daily movements, suggesting that exploratory movements in the region were farther and perhaps bolder due to familiarity with family group members or neighbors captured together in Arkansas. However, Slater et al. (2013) stated that translocated nuthatches did not maintain pair bonds following release and argued that, because of this, future translocations may not need to focus on capturing family groups. We did not track the status of pair bond maintenance, though ongoing monitoring indicates some pair bonds have persisted since capture and some new pair bonds have formed (K. M. Heath-Acre, unpublished data). However, our results show that future translocations of brown-headed nuthatches that make additional efforts to capture as many members of social groups as possible could potentially maximize exploratory movements and dispersal, if this is a desired outcome. Additionally, including whole families might help maintain a more balanced sex ratio, which was skewed in our captures and may be skewed in other resident populations (Norris 1958, Cox and Slater 2007).

All birds were released in one location in 2020 to maximize socialization between released birds in a relatively large, contiguous woodland landscape based on advice of researchers with experience with brown-headed nuthatch reintroductions (J. A. Cox, G. L. Slater, personal communication). In 2021, we added a release site and split the releases between the new site and the original to encourage use of pine woodland that seemed beyond the exploratory movements of 2020 radio-tagged birds. Our strategy was successful; in 2021, birds were found in previously unoccupied available habitat. Future translocations should consider the scale of exploratory movements of their species and find a balance between socialization of birds and exposure to available habitat.

MANAGEMENT IMPLICATIONS

Reintroduction of extirpated species based on extirpated status alone is not prudent. Assessments of habitat availability and sustainability and impact to the source population can help inform translocation efforts. We believe this effort and previous translocation work with brown-headed nuthatches have applications to other small resident songbirds. However, we suggest more intensive tracking efforts than we were able to implement, or automated telemetry, may be needed to better capture dispersal events and improve survival estimates. Considering the high dispersal variance detected in our study, we believe the use of a sCJS model was necessary to estimate survival for the 25 days after release. Given the uncertainty around the status of birds that could not be relocated after release and the short amount of time elapsed since release, the success of this reintroduction is still uncertain. However, longer-term survival and occupancy surveys are ongoing and will be used to evaluate the status of the population.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

We designed our capture and translocation methods to minimize translocation time and stress to the birds and monitored half of the released individuals with radio transmitters according to current guidelines (IUCN/SSC 2013). Banding was conducted under USGS Bird Banding Laboratory permit no. 06547. Trapping, transport, and release was conducted under U.S. Fish and Wildlife Service Migratory Bird permit no. MB61206D-0 and Arkansas Game and Fish Commission Scientific Collection Permit no. 080920219. The University of Missouri and USDA Forest Service Research and Development Animal Care and Use Committees approved all procedures (University of Missouri protocol no. 9887).

DATA AVAILABILITY STATEMENT

Data are provided as private-for-peer review at https://datadryad.org/stash/share/pMwZJWcRrlLTDHkSspHREtbtfcXSHf9h-bePAuk279I. Data are also stored in the Missouri Department of Conservation archives. Requests for these data should be submitted to Tony Elliott, <Anthony.Elliott@mdc.mo.gov>.

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REFERENCES

Arkansas Department of Agriculture. 2020. Arkansas 2020–2029 Forest action plan. Forestry Division. Little Rock, AR, USA. <https://www.agriculture.arkansas.gov/wp-content/uploads/2021/01/Arkansas-Forest-Action-Plan.pdf>. Accessed 13 Dec 2021.

Barron, D. G., J. D. Brawn, and P. J. Weatherhead. 2010. Meta-analysis of transmitter effects on avian behavior and ecology. Methods in Ecology and Evolution 1:180–187.

Bonnot, T. W., D. T. Jones-Farrand, F. R. Thompson III, J. J. Millspaugh, J. A. Fitzgerald, N. Muenks, P. Hanberry, E. Stroh, L. Heggemann, A. Fowler, et al. 2019. Developing a decision support framework for Landscape Conservation Design: integrating dynamic landscape population models and Structured Decision Making. USDA Forest Service General Technical Report NRS-190. Northern Research Station, Columbia, Missouri, USA.

Calenge, C. 2006. The package adehabitat for the R software: tool for the analysis of space and habitat use by animals. Ecological Modelling 197:1035.

Cox, J. A., J. A. Cusick, S. Dietz, M. M. Gray, H. E. Levy, and R. T. Meyer. 2022*a*. Vocalizations help distinguish male and female brown-headed nuthatches (*Sitta pusilla*) in the field. Florida Field Naturalist 50:20–22.

Cox, J. A., M. M. Gray, H. E. Levy, and G. L. Slater. 2022*b*. Cooperative breeding behavior emerges early in restored populations of the brown-headed nuthatch (*Sitta pusilla*). The Wilson Journal of Ornithology 133:634–640.

Cox, J. A., and G. L. Slater. 2007. Cooperative breeding in the brown-headed nuthatch. The Wilson Journal of Ornithology 119:1–8.

Cunningham, R. J. 2007. Historical and social factors affecting pine management in the Ozarks during the late 1800s through 1940. Pages 1–7 *in* Shortleaf pine restoration and ecology in the Ozarks: proceedings of a symposium. USDA Forest Service General Technical. Report NRS-P-15, November 7–9 2006, Springfield, Missouri, USA.

Dickens, M. J., D. J. Delehanty, and L. M. Romero. 2010. Stress: an inevitable component of animal translocation. Biological Conservation 143:1329–1341.

Dobson, A., D. Lodge, J. Alder, G. S. Cumming, J. Keymer, J. McGlade, H. Mooney, J. A. Rusak, O. Sala, V. Wolters, et al. 2006. Habitat loss, trophic collapse, and the decline of ecosystem services. Ecology 87:1915–1924.

Eddleman, W. R., R. L. Clawson, and J. Eberly. 2007. Birds of shortleaf pine forests in Missouri: an historical and contemporary perspective. Pages 168–175 *in* Shortleaf pine restoration and ecology in the Ozarks: proceedings of a symposium. USDA Forest Service General Technical. Report NRS-P-15, November 7–9 2006, Springfield, Missouri, USA.

Ellergren, H. 1996. First gene on the avian W chromosome (CHD) provides a tag for universal sexing of non-ratite birds. Proceedings of the Royal Society B 263:1635–1641.

Gelman, A., and D. B. Rubin. 1992. Inference from iterative simulation using multiple sequences. Statistical Science 7: 457–472.

Gow, E. A., T. W. Done, and B. J. M. Stutchbury. 2011. Radio-tags have no behavioral or physiological effects on a migratory songbird during breeding and molt. Journal of Field Ornithology 82:193–201.

Haas, S. E., J. A. Cox, J. V. Smith, and R. T. Kimball. 2010. Fine-scale spatial genetic structure in the cooperatively breeding Brown-Headed Nuthatch (*Sitta pusilla*). Southeastern Naturalist 9:743–756.

International Union for Conservation of Nature/Species Survival Commission [IUCN/SSC]. 2013. Guidelines for reintroductions and other conservation translocations. Version 1.0. Gland, Switzerland.

Jin, W., H. S. He, S. R. Shifley, W. J. Wang, J. M. Kabrick, and B. K. Davidson. 2018. How can prescribed burning and harvesting restore shortleaf pine-oak woodland at the landscape scale in central US? Modeling joint effects of harvest and fire regimes. Forest Ecology and Management 410:201–210.

Kellner, K. 2021. jagsUI: a wrapper around 'rjags' to streamline 'JAGS' analyses. R package version 1.5.2. <https://CRAN.Rproject.org/package=jagsUI>. Accessed 13 Dec 2021.

Kéry, M., and M. Schaub. 2012. Bayesian population analysis using WinBUGS: a hierarchical perspective. Academic Press, London, UK.

Lipsey, M. K., and M. F. Child. 2007. Combining the fields of reintroduction biology and restoration ecology. Conservation Biology 21:1387–1390.

Lloyd, J. D., G. L. Slater, and S. Snow. 2009. Demography of reintroduced Eastern Bluebirds and brown-headed nuthatch. Journal of Wildlife Management 73:955–964.

McNab, W. H., and P. E. Avers. 1994. Ecological subregions of the United States: section descriptions. WO-WSA-5. U.S. Department of Agriculture, Forest Service Washington, D.C., USA. <http://www.fs.fed.us/land/pubs/ecoregions/index.html>. Accessed 13 Dec 2021.

Missouri Department of Natural Resources. 2016. Missouri Ozarks. Missouri Geological Survey fact sheet number 20. Missouri Department of Natural Resources, Jefferson City, USA.

Norris, R. A. 1958. Comparative biosystematics and life history of the nuthatches Sitta pygmaea and Sitta pusilla. University of California Publications in Zoology 56:119–300.

O'Halloran, K. A., and R. N. Conner. 1987. Habitat used by brown-headed nuthatches. Bulletin of the Texas Ornithological Society 20:7–13.

Plummer, M. 2003. JAGS: a program for analysis of Bayesian graphical models using Gibbs sampling. Proceedings of the 3rd International Workshop on Distributed Statistical Computing. Vienna, Austria; 2003.

Powell, L. A., M. J. Conroy, J. E. Hines, J. D. Nichols, and D. G. Krementz. 2000. Simultaneous use of mark-recapture and radiotelemetry to estimate survival, movement, and capture rates. The Journal of Wildlife Management 64:302–313.

Prasad, A. M., L. R. Iverson, S. Matthews, and M. A. Peters. 2007. Climate change atlas for 134 forest tree species of the eastern United States [database]. Northern Research Station, USDA Forest Service. <https://www.nrs.fs.fed.us/atlas/tree>. Accessed 13 Dec 2021.

PRISM Climate Group. 2023. PRISM Gridded Climate Data. Oregon State University, Corvallis, USA. <http://prism.oregonstate.edu>. Accessed 6 July 2023.

Pyle, P. 1997. Identification guide to North American Birds, Part I. Slate Creek Press. Bolinas, California, USA.

R Core Team. 2022. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reidy, J. L., F. R. Thompson III, G. M. Connette, and L. O'Donnell. 2018. Demographic rates of Golden-cheeked Warblers in an urbanizing woodland preserve. The Condor: Ornithological Applications 120:249–264.

Robbins, M. B. 2020. The status and distribution of birds in Missouri, 2nd Edition. University of Kansas Libraries, Lawrence, Kansas, USA.

Schaub, M., and J. A. Royle. 2014. Estimating true instead of apparent survival using spatial Cormack-Jolly-Seber models. Methods in Ecology and Evolution 5:1316–1326.

Signer, J., J. Fieberg, and T. Avgar. 2019. Animal movement tools (amt): R package for managing tracking data and conducting habitat selection analyses. Ecology and Evolution 2019:9:880–890.

Slater, G. L., J. D. Lloyd, and S. Snow. 2013. Re-introduction of brown-headed nuthatch and Eastern Bluebird to South Florida pine rocklands, USA. Pages 63–67 *in* P. S. Soorae, editor. Global Re-introduction Perspectives: further case studies from around the globe. IUCN/SSC Reintroduction Specialist Group. Abu Dhabi, UAE.

Slater, G. L., J. D. Lloyd, J. H. Withgott, and K. G. Smith. 2021. Brown-headed nuthatch (*Sitta pusilla*) Version 1.1. In Birds of the World (A. F. Poole, Editor). Cornell Lab of Ornithology, Ithaca, New York, USA.

Sollmann, R., B. Gardner, A. W. Parsons, J. J. Stocking, B. T. McClintock, T. R. Simons, K. H. Pollock, and A. F. O'Connell. 2013. A spatial mark–resight model augmented with telemetry data. Ecology 94:553–559.

Stambaugh, M. C. and R. P. Guyette. 2004. Long-term growth and climate response of shortleaf pine at the Missouri Ozark Forest Ecosystem Project. Pages 448–458 *in* Proceedings of the 14th Central Hardwoods Conference. U.S. Department of Agriculture Forest Service, Northeastern Research Station, 1 March 2004, Wooster, Ohio, USA.

Stanton Jr., R. A., D. C. Kesler, and F. R. Thompson III. 2014. Resource configuration and abundance affect space use of a cooperatively breeding resident bird. The Auk 131:407–420.

Streby, H. M., T. L. McAllister, S. M. Peterson, G. R. Kramer, J. A. Lehman, and D. E. Andersen. 2015. Minimizing marker mass and handling time when attaching radio-transmitters and geolocators to small songbirds. The Condor: Ornithological Applications 117:249–255.

Streby H. M., S. M. Peterson, C. F. Gesmundo, M. K. Johnson, A. C. Fish, J. A. Lehman, and D. E. Andersen. 2013. Radio-transmitters do not affect seasonal productivity of female Golden-winged Warblers. Journal of Field Ornithology 84:316–321.

Sydeman, W. J., and M. Güntert. 1983. Winter communal roosting in the Pygmy Nuthatch. Pages 121–124 *in* Proceedings of Snag Habitat Management symposim. U.S. Department of Agriculture Forest Service, Rocky Mountain Forest and Range Experiment Station, 7–9 June, 1983, Flagstaff, AZ, USA.

Vehtari, A., J. Gabry, M. Magnusson, Y. Yao, P. Bürkner, T. Paananen, and A. Gelman. 2020. loo: efficient leave-1-out cross-validation and WAIC for Bayesian models. R package version 2.4.1. <https://mc-stan.org/loo/>. Accessed 13 Dec 2021.

Vehtari, A., A. Gelman, and J. Gabry. 2017. Practical Bayesian model evaluation using leave-1-out cross-validation and WAIC. Statistics and Computing 27:1413–1432.

Wann, G. T., P. E. Howell, J. M. Yeiser, I. B. Parnell, and J. A. Martin. 2020. Estimating harvest rate and the effects of hunting pressure on northern bobwhite survival. Wildlife Biology 2020:1–11.

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