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Effectiveness and Accuracy of Track Tubes for Detecting Small-Mammal Species Occupancy in Southeastern Herbaceous Wetlands and Meadows

Duston R. Duffie[1,2,*], Robert A. Gitzen[2], Nicholas W. Sharp[1], and Amy J. Turner[3]

Abstract - As a non-invasive approach for sampling small mammals, track tubes may be especially useful in species occupancy studies that do not require marking of individuals. However, such studies may involve significant uncertainty in identifying many tracks to species. Using 37 study sites in eastern Alabama and Tennessee, we compared relative differences in detection probabilities with track tubes vs. live traps for *Peromyscus* (deermice), *Oryzomys palustris* (Marsh Rice Rat), and *Sigmodon hispidus* (Hispid Cotton Rat). In analyses that ignored identification uncertainty or that used false-positive occupancy models to address this uncertainty, track tubes and live traps had similar detection probabilities. When uncertain detections were omitted from analysis, effective detectability was lower with track tubes. False-positive occupancy modeling indicated that track-identification uncertainty could not be ignored, as there was a non-zero probability of false-positive detections. False-positive occupancy designs have high relevance to track-tube studies; in addition, such studies should ensure that track identification is done under the oversight of an experienced tracker.

Introduction

Although live traps are a highly useful approach for sampling wild small-mammal populations, biologists have access to a rapidly expanding toolbox of potential non-invasive alternatives, such as genetic sampling approaches (e.g., Russello et al. 2015), camera surveys (DeSa et al. 2012, McCleery et al. 2014), and hair sampling with morphological species identification (e.g., Goldstein et al. 2014). Track tubes, which are passive detection devices that record tracks of animals entering the tubes, are a non-invasive alternative used effectively in many small-mammal field studies (Drennan et al. 1998, Glennon et al. 2002, Nams and Gillis 2003). In contrast to live trapping (Sikes et al. 2016), track tubes involve no risk of injury or death for animals, a major advantage in studies of protected species (Pries et al. 2009, Stolen et al. 2014, Wilkinson et al. 2012). This advantage is important throughout much of the southeastern USA, given the high risk of predation by invasive *Solenopsis invicta* (Buren) (Red Imported Fire Ants) on animals confined in live traps (Kraig et al. 2010, Mabee 1998, Masser and Grant 1996).

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[1] Alabama Department of Conservation and Natural Resources Division of Wildlife and Freshwater Fisheries, 21453 Harris Station Road, Tanner, AL 35671. [2] School of Forestry and Wildlife Sciences, Auburn University, 602 Duncan Drive, Auburn, AL 36849. [3] The University of the South, 735 University Avenue, Sewanee, TN 37383. [*] Corresponding author - drd0006@tigermail.auburn.edu.

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Conversely, direct capture allows biologists to obtain accurate morphological identification of most species, facilitates collection of tissue and fecal samples, enables determination of sex and reproductive status, and allows application of tags or other marks for identifying recaptured individuals (Sheppe 1965, Sikes et al. 2016). However, these advantages of live traps may not be relevant to many studies using occupancy-modeling approaches to assess patch-level species occurrence (MacKenzie et al. 2002). The basic occupancy approach uses binary species-level detection data (zero detections vs. at least 1 detection of the species during the survey) from repeated surveys of sites to estimate the per-survey probability of detecting the species at an occupied site. By incorporating detection probability into the statistical model, occupancy modeling accounts for potential false absences (i.e., sites where the target species was present but not detected) in making inference about occupancy (MacKenzie et al. 2002). Achieving suitably precise estimates of occupancy parameters requires using a method that produces high overall detection probabilities.

Comparisons of observed species richness, raw detection rates, and correlations between track-tube indices and trapping-based population estimates suggest that track tubes often may achieve equal or higher species-level detection probabilities compared to live traps (Palma and Gurgel-Gonçalves 2007, Wiewel et al. 2007, Wilkinson et al. 2012). However, except in studies of subspecies of *Peromyscus polionotus* (Wagner) (Beach Mouse) in coastal dunes in the Southeast US (Pries et al. 2009, Stolen et al. 2014) and an example analysis by Stanley and Royle (2005), previous studies have not analyzed track-tube data with approaches that explicitly incorporate individual or species-level detection probability. Biologists planning small-mammal occupancy studies in the Southeast and other regions would benefit from direct comparisons of detection probabilities between methods and a better understanding of interspecific variation in their relative effectiveness.

Although identification of live animals based on morphology may be imperfect for some small-mammal species, identification uncertainty is likely to be a more frequent problem in track-tube studies given that identifications are based only on track characteristics that can be highly similar among small-mammal species (Elbroch 2003). Track-plate studies with larger taxa indicate that track identification accuracy can vary significantly among observers, and experienced observers usually are needed to ensure that tracks are identified to species correctly (Evans et al. 2009, Stander et al. 1997, Zielinski and Schlexer 2009). Accurately discriminating some small-mammal species may require fine-scale measurements from clear tracks (Palma and Gurgel-Gonçalves 2007, Stolen et al. 2014). Yet, over-tracking, moisture, and smudging from non-target animals often can hinder track clarity. Except when focused on species assemblages in which the target species can be identified with high confidence (Mills et al. 2016, Wilkinson et al. 2012), track-tube studies frequently face uncertainty and potential mistakes in identifications.

To deal with identification uncertainty, some track tube studies have omitted uncertain identifications from species-specific analyses or grouped identifications of problematic species (Glennon et al. 2002, Wiewel et al. 2007). Other studies have not explicitly discussed whether any identifications were uncertain. In occupancy modeling, even a low rate of false-presence observations (misidentifications leading to mistakenly "detecting" a species at a site where it is not present) will cause estimator bias (McClintock et al. 2010, Miller et al. 2011, Royle and Link 2006). When data includes a mix of certain and uncertain identifications of a species or supplemental information is available about probability of errors, approaches for explicitly modeling probability of false-presence errors are now readily accessible (Chambert et al. 2015, Ferguson et al. 2015, Miller et al. 2011; see Stolen et al. 2014 for a track-tube application with *Peromyscus polionotus niveiventris* (Chapman) [Southeastern Beach Mouse]).

We compared the relative performance of track tubes vs. Sherman live traps for assessing small-mammal occupancy in herbaceous wetlands and meadows in the Southeast. As our primary comparison, we examined differences between the 2 methods in per-night detection probability for 3 widespread southeastern rodent taxa. In addition, we examined between-observer consistency in track identification. We implemented alternative strategies for dealing with uncertainty in track identifications (false-positive models vs. omitting uncertain detections vs. ignoring uncertainty) and examined whether estimates of detection probabilities from track-tube sampling were sensitive to the choice among these strategies.

Field-Site Description

Data for this study were collected as part of an assessment of current occurrence of *Zapus hudsonius* (Zimmermann) (Meadow Jumping Mouse) in eastern Alabama and at Arnold Air Force Base (AFB) in Tullahoma, Coffee, and Franklin counties, TN. Sites were selected based on historical records and presence of moist soils and dense cover of herbaceous or shrubby vegetation (Whitaker 1972). Therefore, our study focused on grassy meadows along marshes, ponds, and streams, moist herbaceous areas with a forest overstory, and abandoned hayfields. We sampled 37 sites in 3 groups of surveys in 2015–2016 (Fig. 1). During June–August 2015, we sampled 17 sites in Lee and Chambers counties in southeastern Alabama (Alabama 2015 group). In July–August 2016, we sampled 11 sites in Jackson, Cherokee, De Kalb, and Lee counties; most of these sites were in northeastern Alabama (Alabama 2016 group). We sampled a third group of 9 sites at Arnold AFB during July 2016.

Methods

Field methods and track identification

At each site, we used folding Sherman live traps (7.62 cm x 8.89 cm x 22.86 cm, Model LFA Folding Trap; H.B. Sherman Trap Inc., Tallahassee, FL) and track tubes to sample small mammals. We built track tubes following a modified version of Glennon et al.'s (2002) design, using two 30-cm sections of vinyl rain gutter taped along one edge to form a tube. We capped one end of this tube using metal flashing and duct tape to increase rain resistance (Fig. 2); this modification did not appear to affect the detection of small or meso-sized mammals during informal comparisons of track tube designs We created the tracking substrate using a kerosene lantern to soot ~12 cm of the end of the metal flashing lining the bottom of the tube that was nearest the capped portion of the tube and a 15 cm x 7 cm strip of Contact© paper shelf-liner (Kittrich Corporation, Pomona, CA) attached to the other end of the metal flashing as a surface (track plate) for collecting tracks.

Each site was trapped with 24 live traps and 24 track tubes placed in a grid with 10 m between trap stations. Most sites were sampled with 3 x 16 or 4 x 12 grids; several sites with narrow riparian corridors were sampled with 2 x 24 grids. One trap (live trap or track tube) was placed at each station, with trap type alternating between stations. Both trap types were baited with black oil sunflower seeds. To reduce problems with Red Imported Fire Ants in Alabama sampling in 2015 and at Arnold AFB, the area underneath each trap (approximately 15 cm x 36 cm) was dusted with a layer of Sevin Dust© (Carboxyl 5%; Kraig et al. 2010).

We trapped each site for 1 session of 4 consecutive nights and checked live traps and track tubes each morning. We removed the paper from track plates with track detections and preserved them within clear plastic sheet protectors for later analysis. We then placed new paper onto the track plate and reset the tube. We identified

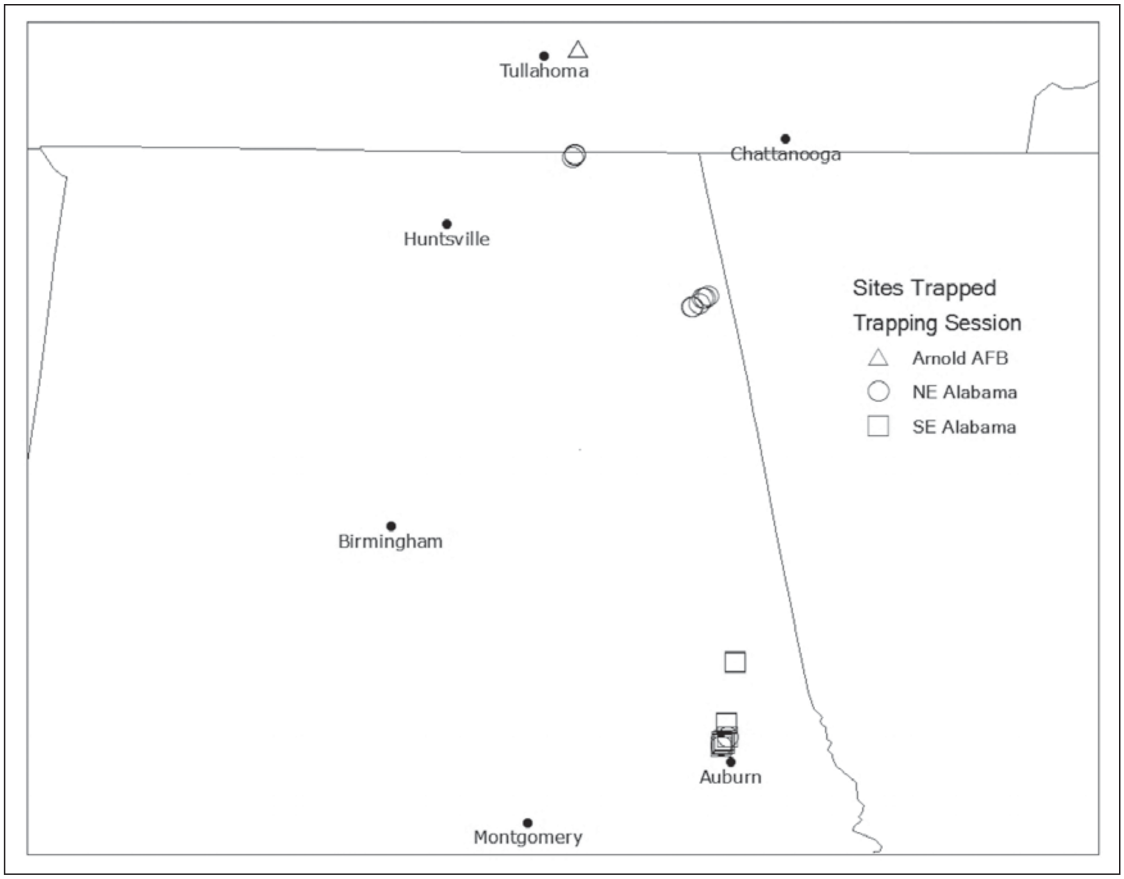

Figure 1. Location of 37 study sites sampled for small mammals during 2015–2016 and used for comparison of Sherman live traps and track tubes. Sampling occurred during 2015–2016 at Arnold Air Force Base in Tennessee (9 sites), northeast Alabama (11 sites), and southeast Alabama (17 sites).

captured animals to species, with hind-foot length, body length, and tail length measured as necessary for identification.

We identified tracks to species or to the lowest taxonomic level possible with a measure of high, medium, or low confidence of track identification at each taxonomic level based on presence and clarity of diagnostic features. Diagnostic

Figure 2. Track-tube design used for sampling small mammals for comparison with Sherman live trapping at 37 Alabama and Tennessee study sites, 2015–2016. Design was based on Glennon et al. (2002) but modified to reduce effects of rain splatter and feeding debris by capping one end with metal flashing and duct tape. Cotton Rat tracks are visible on the track plate.

characters were derived from our reference library of known tracks created from live captures during this and previous studies and from multiple tracking publications that described differences in foot morphology among species (Fig. 3; Elbroch et al. 2012, Taylor and Raphael 1998, Van Apeldoorn et al. 1993). All tracks were identified by one primary observer (D. Duffie) with 1 yr of track-identification experience, who was trained by an experienced tracker (an individual trained and experienced in the identification of tracks and sign; N. Sharp, 6.5 yrs experience; certified Level III in the CyberTracker evaluation system [see Evans et al. 2009]) who also served as a secondary observer. A subset of 58 track plates from 1 trapping group out of the total sample of 390 track plates was independently analyzed by both observers to evaluate accuracy.

Statistical analysis

To assess whether there were systematic differences in the number of species detected by each method, we calculated the difference in the overall raw count of rodent and shrew species detected with live traps vs. track tubes (high and medium confidence detections pooled) for each site, and summarized the average site-level difference. For this and subsequent analyses, we pooled all observations of *Peromyscus* spp. (deermice) into a single category. Other species present in our study region and potentially confused with *Peromyscus*, such as *Ochrotomys nuttalli* (Harlan) (Golden Mouse) or *Reithrodontomys humulis* (Audubon and Bachman) (Eastern Harvest Mouse), were not captured in live traps, and we were

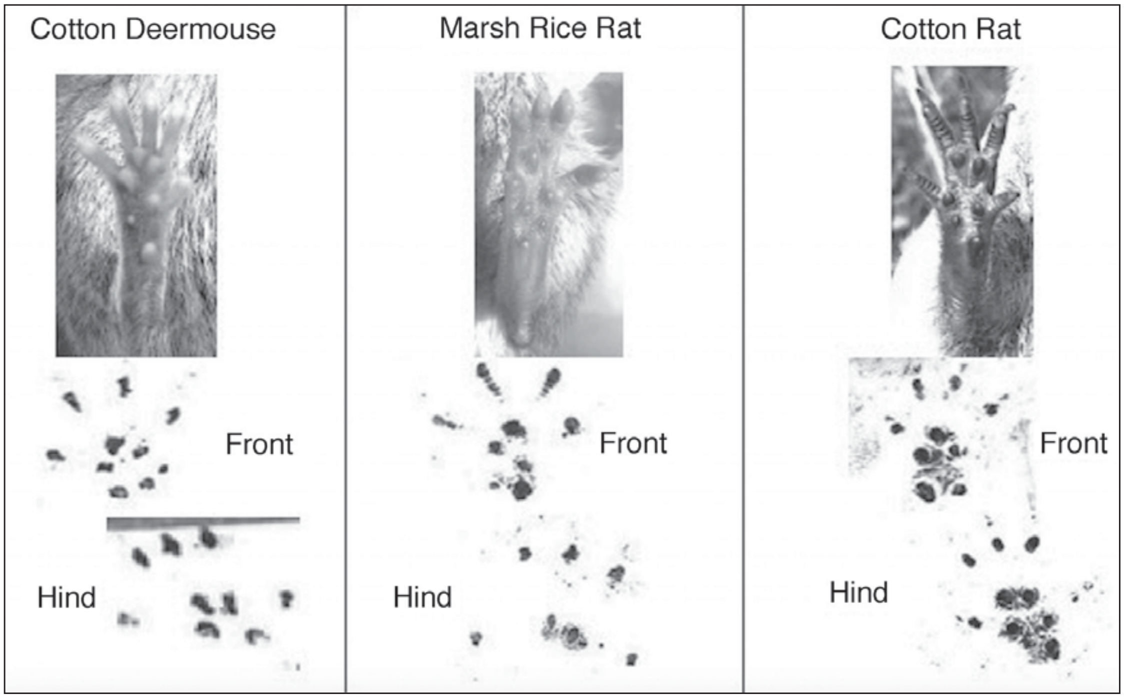

Figure 3. Hind feet and example tracks from the 3 most commonly detected small-mammal species at Alabama study and Tennessee study areas, 2015–2016 (pictures and tracks not to scale). As shown, differences in foot morphology can be used to accurately distinguish these species from tracks.

confident that they could be distinguished from deermice based on differences in foot morphology seen in our track library. Although we did not identify more than 1 deermouse species per site from live trap captures, we could not reliably identify deermouse tracks to species across all sites. Detections of taxa other than rodents and shrews were considered incidental and omitted from analysis.

We used single-season occupancy models (MacKenzie et al. 2002) to quantify the relative effectiveness of track tubes vs. live traps for assessing occurrence of *Sigmodon hispidus* (Say and Ord) (Hispid Cotton Rat, hereafter Cotton Rat), *Oryzomys palustris* (Harlan) (Marsh Oryzomys or Marsh Rice Rat, hereafter Rice Rat), and deermice in our study area. Because of our focus on site-level species occurrence, we use the term "detection" to denote a trap night with at least 1 capture or track identification of a species in at least 1 trap or tube in the array. For each study site, encounter histories (combinations of binary values for each trap night indicating whether the species was detected at the site) were compiled separately for track tubes and for live-trap detections. An 8-digit encounter history was formed for each site by joining the 4-night encounter histories from live traps with those from track tubes.

We performed one set of occupancy analyses that assumed no false-positive detections in the track-tube encounter histories and examined whether our results were sensitive to our confidence threshold of track identifications. We formed 3 alternative detection histories: one incorporating all track tube detections of each species (high, medium, low confidence pooled), one omitting low-confidence detections, and one omitting low- and medium-confidence track detections. We analyzed each alternative dataset separately using a multi-species Bayesian hierarchical occupancy model, with posterior distributions for parameters estimated with program JAGS through the "rjags" package (Plummer 2016) in program R (R Core Team 2016). We use Bayesian modeling for all analyses because the incorporation of non-informative prior distributions stabilized estimates of false-positive detection probabilities (sensu Gelman et al. 2008) and increased modeling flexibility by allowing straightforward incorporation of random effects. Fixed-effect parameters included species-specific, study-wide occupancy probabilities, species-specific average study-wide detection probabilities, and parameters allowing for a species-specific change in detectability from the first trap night to the subsequent 3 trap nights of each trap session. We incorporated an additional random effect to model heterogeneity among sites in detection probability for each species (such as due to among-site variation in abundance). We included a fixed-effect parameter to model the relative difference in detection probabilities for track tubes vs. live traps for each species; detection probability was modeled as an additive function of these parameters on the log-odds scale as in standard logistic regression. We used non- or weakly informative prior distributions for each parameter in the Bayesian analyses. Reported results are summaries of posterior distributions estimated with 30,000 total samples per parameter (3 Markov chain Monte Carlo chains of 50,000 samples each after chains converged satisfactorily, with every 5th sample retained). We estimated posterior distributions for the species-specific and overall average difference between methods on the odds-ratio scale ([odds of detection with track tubes] / [odds of detection with live traps]; odds ratio =

1.0 if the 2 methods have identical detection probabilities). For all Bayesian analyses, we examined alternative weakly informative prior distributions to confirm that our results were not sensitive to such choices, and assumed adequate model fit based on graphical examination of model residuals.

To explicitly account for and estimate the probability of site-level false-positive detections with track tubes, we conducted a second analysis that integrated the 2 types of "site confirmation" (Chambert et al. 2015) false-positive occupancy approaches outlined by Miller et al. (2011). Live-trap detections were treated as certain detections with no chance of false-presence detections. Track-tube data were treated as having 2 types of detections: certain detections, i.e., at least 1 high-confidence identification of the species during the survey; and uncertain detections, i.e., only medium- or low-confidence identifications recorded for that survey. Within this framework, false-positive detections were possible at a site only if there were no certain detections of the species from either method during the 4-night visit. Adapting computer code from Chambert et al. (2015), we expanded the general Bayesian model and JAGS code used for our first set of analyses by incorporating 2 additional sets of species-specific parameters: probability of a false-positive detection and probability that a correctly identified track-tube detection at an occupied site would be classified as certain (identified with high confidence). We modeled both types of parameters as constant across all track-tube surveys and gave them Uniform (0, 1) prior distributions.

Results

During 2015–2016, our total trap effort included 3168 trap nights (1584 live-trap trap-nights and 1584 track-tube trap-nights) in the Alabama 2015 group of sites, 2112 trap nights (1056 live-trap trap-nights and 1056 track-tube trap-nights) in the Alabama 2016 group, and 1728 trap-nights (864 live-trap trap-nights and 864 track-tube trap-nights) at Arnold AFB, with a nominal trap effort of 96 trap nights per method per site (4 nights x 24 traps or track tubes per night). Across all sites, we detected 6 species of rodents (Cotton Rat, Rice Rat, *P. leucopus* (Rafinesque) [White-footed Deermouse], *P. gossypinus* (LeConte) [Cotton Deermouse], *Neotoma floridana* (Ord) [Eastern Woodrat], and *Microtus pinetorum* (LeConte) [Woodland Vole]) and 1 shrew that was not identified to species; we had no detections of Meadow Jumping Mouse (Table 1). Track-tube results also recorded 3 identifications of *Sylvilagus* sp. (rabbit) and incidental identifications of *Procyon lotor* (L.) (Raccoon) and *Didelphis virginiana* (Kerr) (Virginia Opossum). At the site level, there was no significant difference in the number of species detected by each trapping method (average difference in species, live traps vs. track tubes: mean = 0.08 species; 95% CI = -0.14, 0.30; n = 37). For the most frequently captured species (deermice and rats), across all sampling there were more total track-tube identifications of each species than live-trap captures when all track confidence levels were included (Table 1). However, when considering only high-confidence track-tube detections, there were fewer track-tube identifications than live-trap captures for Rice Rats and deermice.

Of the subset of 58 track plates that were analyzed by a second observer, 35 contained small-mammal tracks. The 2 observers had 100% agreement on identifications at the levels of mammalian order (rodents vs. shrew vs. each incidentally detected order) and therefore to the level of family, as there were no orders for which we detected multiple families. For 34 of the 35 plates, the observers' identifications were consistent to subfamily, which distinguished Neotominae (in our study, deermice and Eastern Woodrat), Arvicolinae (voles), and Sigmodontinae (Rice Rats and Cotton Rats). At the genus level, the 2 observers agreed on 16 of the 35 track plates with the same level of confidence and 17 track plates with different levels of confidence, for an overall 94% agreement. To species, observers agreed on 12 track plates with the same level of confidence and 14 track plates with different levels of confidence. For 7 of the 9 plates for which observers did not agree to species, the discrepancy was because the more experienced observer provided a species identification while the second observer labeled the plate as providing insufficient information.

Posterior median estimates of occupancy for the 3 most commonly detected taxa did not show consistent differences among alternative approaches to handling identification uncertainty, but precision was low (Fig. 4). Average per trap-night true-positive detection probability with live traps was highest for Cotton Rat (estimates from false-positive occupancy model: posterior median = 0.55; 95% credible interval = 0.18, 0.83) compared to Rice Rat (median = 0.19; 95% CI = 0.06, 0.49) and deermice (median = 0.27; 95% CI = 0.08, 0.59). When all tracks, regardless

Table 1. Live-trap captures and track-tube identifications by confidence level of small-mammal species detected during sampling of 37 sites in Alabama and Tennessee, 2015–2016.

Area	Species	Live trap	Track tube (high confidence)	Track tube (all confidence)
Alabama 2015				
	Shrew sp.	0	1	1
	Deermouse sp.	0	4	13
	Cotton Deermouse	4	0	0
	Eastern Woodrat	1	1	1
	Marsh Rice Rat	41	18	43
	Cotton Rat	80	83	132
Alabama 2016				
	Deermouse sp.	2	9	13
	Cotton Deermouse	7	0	0
	Eastern Woodrat	0	1	1
	Marsh Rice Rat	4	0	2
	Cotton Rat	6	4	6
Arnold AFB				
	Deermouse sp.	0	34	47
	White-footed Deermouse	40	0	0
	Cotton Rat	3	4	6
	Woodland Vole	1	0	0
Total		189	158	265

of confidence level, were included in analyses that either ignored identification uncertainty or used false-positive modeling, per trap-night odds of detection did not differ between track tubes vs. live traps (Fig. 5). However, when low- or low- and medium-confidence track-tube detections were omitted and all track detections were assumed certain, odds of detection with track tubes on average were 55% lower than odds with live traps. This difference was most pronounced with Rice Rats (Fig. 5); they were detected only with live traps at 6 of the 19 sites where

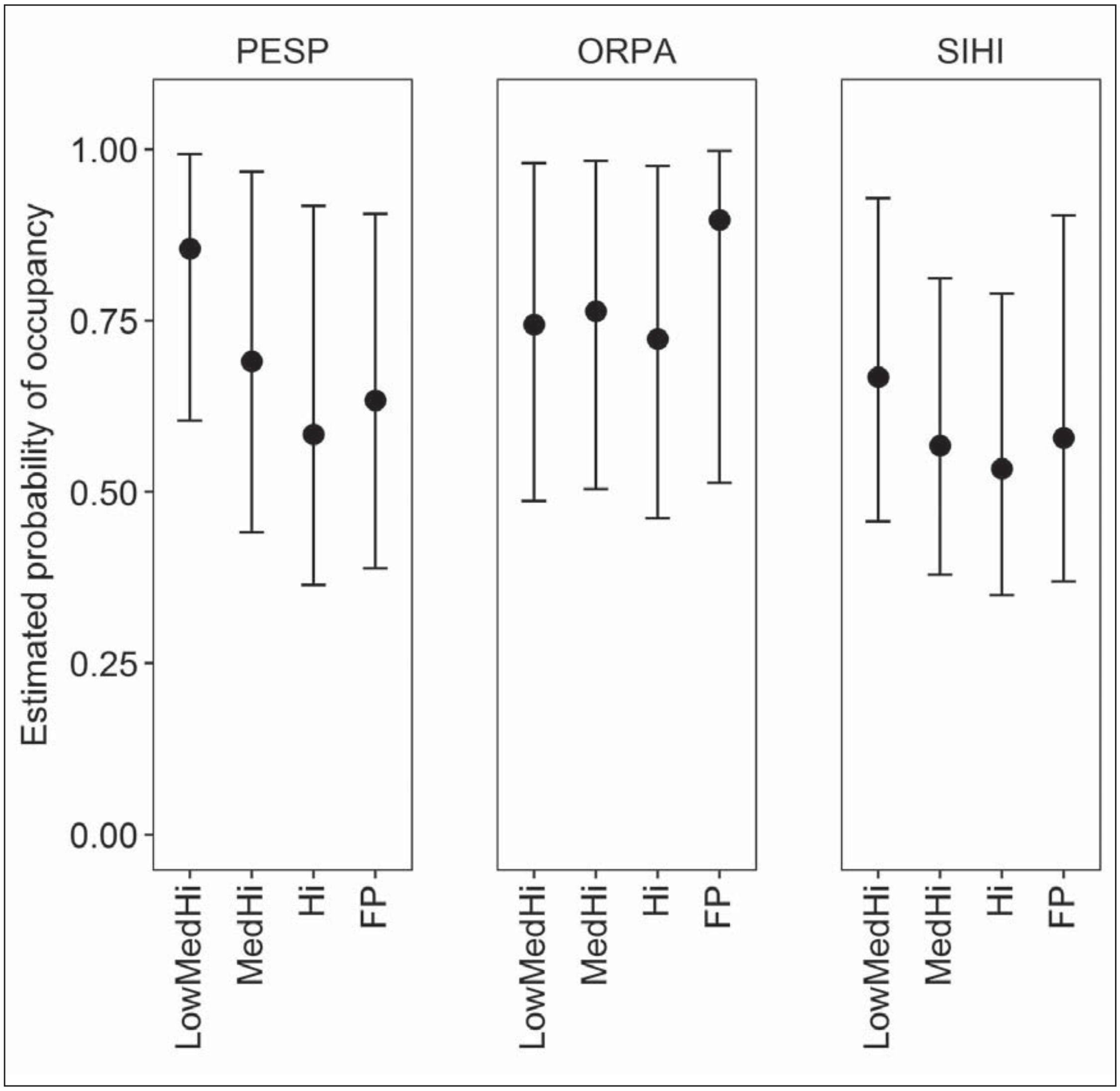

Figure 4. Estimated posterior distribution, probability of occupancy, 2015–2016, using data from sampling with Sherman live traps and track tubes at 37 sites in Alabama and Tennessee, for deermice (PESP), Marsh Rice Rat (ORPA), and Cotton Rat (SIHI), by data set analyzed (point = posterior median, error bars = 95% credible intervals). Data sets differed by how uncertainty in track-tube detections was handled; live-trap detections were included in all data sets. "LowMedHi" = all track-tube detections included; "MedHi" = low-confidence track-tube detections omitted from analysis; "Hi" = low- and medium-confidence track-tube detections omitted; "FP" = all track-tube detections included but with low- and medium-confidence detections treated as uncertain and with some probability of being false-positive detections.

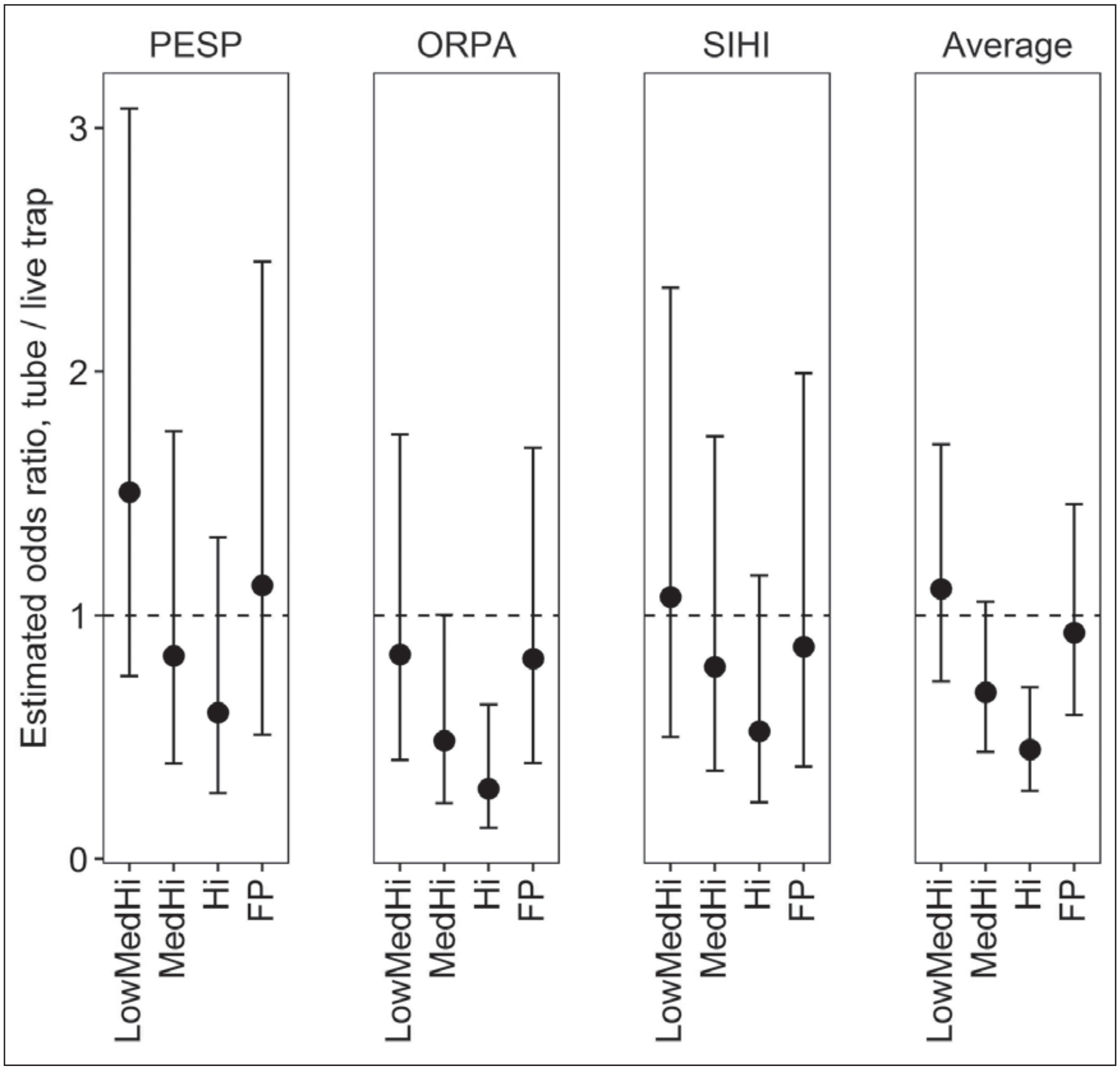

Figure 5. Estimated posterior distribution for method odds ratio ([per-trap night odds of detection with track tubes] / [odds of detection with live traps at an occupied site]), for deermice (PESP), Marsh Rice Rat (ORPA), and Cotton Rat (SIHI), by data set analyzed (point = posterior median, error bars = 95% credible intervals). Data are from sampling of 37 sites in Alabama and Tennessee, 2015–2016. Odds ratio of 1.0 (horizontal reference line) equals no difference in detection probability between methods; odds ratio < 1.0 = higher detection probability with live traps; odds ratio > 1.0 = higher detection probability with track tubes. See Figure 4 for additional information.

Table 2. Number of sites with at least 1 detection of each species categorized by method(s) of detection and track identification confidence (*n* = 37 sites sampled in Alabama and Tennessee, 2015–2016).

Species	Live trap only	Track tube only (high confidence)	Track tube only (all confidence)	Both trap types (high confidence)	Both trap types (all confidence)
Deermouse sp.	3	4	10	8	9
Marsh Rice Rat	6	0	1	11	12
Cotton Rat	4	1	4	11	12

observed, vs. no sites where they were detected only at a high confidence level with track tubes (Table 2). Cotton Rat detectability varied little between methods. Of the 20 sites at which Cotton Rats were detected, they were detected with both methods at 12 sites, while they were detected only with live traps at 4 sites and only with track tubes at 4 sites (Table 2). However, of the 22 sites where deermice were detected, they were recorded only with track tubes at 10 sites (including 7 of 8 Alabama sites in 2015), vs. 3 sites where they were detected only with live traps.

False-positive occupancy modeling indicated that misidentification and potential false-presence observations were a concern for deermice (posterior median probability of false-positive detection = 0.11 [0.04, 0.30]) and Cotton Rats (0.05 [0.01, 0.21]). By definition, false-positive detections were possible only at sites where no certain detections were obtained. For deermice, there were 6 sites where the only detections recorded were uncertain (medium- or low-confidence track identifications), while for Cotton Rats, there were 3 sites where only uncertain detections were recorded. However, for Rice Rats, except for 1 site with only an uncertain detection, at all other sites at least one certain detection (trap capture or high-confidence track identification) was recorded. The data did not provide useful information about the probability of false-positive detections of Rice Rats (posterior median = 0.07 [0.002, 0.91]). The estimated probability that a true-positive track detection would be classified as certain (high confidence) was highest for Cotton Rats (0.82 [0.68, 0.92]), intermediate for deermice (0.73 [0.56, 0.87]), and lowest for Rice Rats (0.52 [0.35, 0.70]).

Discussion

In our sampling, track tubes detected similar numbers of species per site compared to live traps. When uncertainty in track identifications either was ignored or was explicitly addressed with false-positive models, per-trap-night odds of detection were similar between methods. This result indicates that track tubes are an effective and viable alternative to live trapping for occupancy studies of mice and rats in our study system, particularly given other advantages of track tubes. They eliminate meaningful risk to animals, reduce some study costs significantly (e.g., our costs were ~$5 US per track tube for supplies and building time versus purchasing Sherman live traps currently priced $20 US per trap), and offer greater flexibility in frequency and timing of field checks compared to live traps (e.g., Nams and Gillis 2003). In our preliminary sampling, sooted track tubes were a reliable detection method during dry weather for up to 6 trap nights before track plates needed replacement. However, in our wet-meadow study sites, daily track-plate replacement was required during periods of heavy rainfall. In wetland areas where traps are consistently exposed to water, track tubes may not be a useful technique (DeSa et al. 2012).

A more general issue raised in our study is track identification uncertainty. The utility of track tubes depends on whether or not tracks can be reliably identified to the taxonomic level needed by the study and whether the study uses appropriate approaches for addressing identification uncertainty when present. Experienced and well-trained observers, a reference library of known tracks, and accurate diagnostic criteria (e.g., unique track morphology) usually are needed to identify tracks to species (DeSa et al. 2012, Evans et al. 2009, Zielinski and Schlexer 2009). Quality-control strategies such as repeated accuracy checks and tests of among-observer agreement are recommended whenever a track-tube study faces identification uncertainty. Because of the importance of observer experience for accurate track identification, track tube studies should report the experience level of personnel overseeing track identification, ideally using tracker-certification levels (Evans et al. 2009).

Even for experienced observers, tracks of some species may be too similar to distinguish with certainty, and some tracks will be incomplete or have imperfect clarity. Therefore, besides attempting to maximize accuracy of identifications, track-tube studies also need strategies for dealing with unresolved uncertainty. Based on our estimates of the per-survey probabilities of false-positive detections for deermice and Cotton Rats, ignoring uncertainty in identifications would not be justified in our study system because standard occupancy estimators would be biased (Royle and Link 2006, McClintock et al. 2010, Miller et al. 2011). Simply omitting uncertain track identifications is a suboptimal approach if it lowers effective detection probabilities substantially (Miller et al. 2011), as was observed with our data (Fig. 4). This reduction in detection probability for track tubes would lead to a need for more survey nights per site to maintain precision of occupancy estimates (MacKenzie et al. 2002). In contrast, in the false-positive analysis, which did not discard uncertain identifications but did address uncertainty, there was no loss of effectiveness with track tubes relative to detection probabilities of live traps.

Our results reinforce the potential utility of false-positive models for occupancy studies using track tubes (Stolen et al. 2014). Although the primary purpose of these models is to reduce estimator bias for inference about occupancy, they also produce quantitative measures of identification uncertainty (false-positive detection probabilities and related parameters) that integrate observer accuracy and inherent biological constraints on accuracy (e.g., due to species overlap in key track characteristics). In our study, the estimated probability of identifying a true-positive detection with certainty was much lower for Rice Rats than Cotton Rats, despite general similarity in tracks of these 2 species. This finding may be a function of the higher relative abundance of Cotton Rats in our study, as more tracks per survey equals higher probability of obtaining at least one high-confidence detection. Along with this, Cotton Rats are more easily identified due to their prominent, paired metatarsal pads.

Biologists considering use of track tubes in small-mammal occupancy studies should carefully review available study-design guidance related to false-positive approaches, as the choice of approach and allocation of field effort depends on the specific details of each study situation (Chambert et al. 2015, Clement 2016, Miller et al. 2011). For example, using a combination of track tubes and direct capture could seem like a sensible approach when there is concern about accuracy of track misidentification. However, combining methods would be redundant if many track identifications for a given species are certain. Even when that is not the case, optimal allocation of effort between sampling methods could favor using both methods, only track tubes, or only live traps, depending on expected probabilities of occupancy, true-positive detections, and false-positive detection (Clement 2016). Intuitively, incorporating track tubes into occupancy studies along with or in place of direct-capture methods would seem to have utility mainly when tracks of all potentially present taxa of interest can be identified with relatively low probability of false-positive identifications. For example, even in single-species scenarios, optimal allocation would favor putting all effort into direct-capture surveys when per-survey false-positive detection probability is >0.01 if per-survey probability of true-positive detection is <0.4, direct-capture and track-tube costs per survey are similar, and direct-capture surveys have no chance of species misidentification (Clement 2016).

Several potential extensions discussed by Miller et al. (2011) and Chambert et al. (2015) for false-positive analyses would be applicable for studies such as ours. The basic false-positive occupancy model could be expanded to allow multiple categories of uncertainty, to model individual track identifications rather than binning them into a single detection state for each survey, and to consider other aspects of potential identification errors. In our study, nearly all uncertain detections of Rice Rats and Cotton Rats were identified with certainty to subfamily level. We could be certain, for example, that an uncertain identification of a Rice Rat was either a correct identification of a Rice Rat or a misidentification of a Cotton Rat. Incorporating this reciprocal misidentification constraint with such co-occurring species pairs would have utility in track-tube studies as well as direct-capture studies dealing with identification uncertainty (e.g., Cotton Mouse vs. White-footed Mouse; Fernandes et al. 2010).

Conclusions

Track tubes are a useful non-invasive approach in occupancy studies of small mammals in the Southeast. However, their utility depends on whether taxa can be identified accurately to the level needed by the study and whether identification uncertainty can be handled appropriately. Extensions to existing false-positive occupancy models are an area of active research (Chambert et al. 2015), and studies utilizing track tubes will benefit from these developments. Still, it will remain important to minimize uncertainty by using study protocols that produce high detection probabilities and high-quality species identifications. To ensure suitable accuracy in any track-tube study, track identification should be done under the training and oversight of an experienced tracker and with appropriate checks of observer accuracy. We recommend that tracking studies document the experience level of key project personnel, the degree of identification uncertainty present in their study, and the steps taken to address that uncertainty.

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