

**SMALL MAMMAL BIODIVERSITY AND FOREST FRAGMENT HEALTH
IN THE MID-ATLANTIC**

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Honors Bachelor of Sciences in Wildlife Conservation with Distinction.

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ABSTRACT

With the ever increasing trend in urbanization and the associated high level of human influence, there is a growing ecological interest in potential impacts such as; biodiversity loss, altered trophic interactions, increased disease incidence, and altered resource competition. Urban forest fragments provide some of the only remaining natural habitat for mammals in Northern Delaware, but little is known about mammalian biodiversity in these systems. Previous studies in forest systems have correlated the loss of small mammal biodiversity to a decrease in various ecosystem functions, and overall ecosystem health. Given the importance of ecosystem health in maintaining human services such as disease mitigation, pest reduction, and crop pollination, it is important to improve our knowledge of small mammal biodiversity in the region, and elucidate how that biodiversity is linked to forest health. In collaboration with the Forest Fragments in Managed Ecosystems (FRAME) project at the University of Delaware we measure the biodiversity of small mammals in local forest fragments, and compare these values to a Principal Components Analysis of previously collected forest health metrics, such as invasive plant distributions, snail densities, and calcium availability. Simple linear regression showed a significant increasing trend in the biodiversity of small mammals as forests approached mature stages and fewer invasive species were present. We used non-invasive track tubes to “capture” small mammal presence and in the course of our research improved upon previous designs to improve effectiveness in areas with high densities of raccoons

(*Procyon lotor*). Our findings suggest that small mammal biodiversity is a potential indicator of forest health in the mid-Atlantic region. Our results also serve as a baseline for future research to better understand how ecosystem services are altered in the landscape.

Chapter 1

USING SMALL MAMMAL BIODIVERSITY AS AN INDEX OF FOREST FRAGMENT HEALTH

INTRODUCTION

Urbanization is a growing form of land modification, with more than 82.1% of the U.S. population residing in urban areas (UN Population Division 2010). There are five identified types of land-uses based on the intensity of human influence: natural landscapes, managed landscapes, cultivated landscapes, suburban landscapes, and urban landscapes (Forman and Godron 1986), of these, urban landscapes experience the most intense human influence and are dominated by residential and commercial buildings, roads, and paved surfaces. Properties that best distinguish urban from natural landscapes include low connectivity among habitat patches, altered succession, and invasion of nonnative species (Trepl 1995; Grimm et al. 2000; McKinney 2002)

Given the increasing trend in urbanization and the associated high level of human influence, ecologists have developed a discipline called urban ecology which focuses on ecological research in an urban setting. Research in this discipline often includes exploring the ecological impact of urbanization on biodiversity loss, trophic interactions, disease (both human and wildlife), resource competition, and the overall quality of the remaining habitat (Forman and Godron 1986, Fahrig 1997; Marzluff 2001, McKinney 2002, Stochat et. al. 2006).

Urban landscapes often lack large contiguous forested areas and instead remaining trees are isolated into smaller forest fragments. Gascon et. al (1999) described this habitat fragmentation as the end result of human settlement and resource extraction which has created small isolated natural areas in a sea of developed land. Given the high level of urbanization in the mid-Atlantic, these urban forest fragments provide some of the only remaining habitat for mammal, bird, and insect species in Northern Delaware. Unfortunately, there is a wide range of forest health in these fragments and some may act as habitat sinks or be unviable for sustaining wildlife populations. To appropriately manage these fragments it is important for managers to be able to understand which are in good “health” and likely acting as a population source, and which are in poor “health” and possibly acting as a population sink.

However, “Forest Health” is an ambiguous term, as this concept often refers to an a priori definition, thus coming up with a standard form of measurement has been a challenge. Varying perspectives of forest values and time scales over which change is evaluated further contribute to this ambiguity (McLaughlin and Percy 1999).

Even so, widespread forest decline has encouraged the increased assessment and monitoring of forest health for adequate resource management.

Rapport (1995) discusses that ecosystem health can be measured by observing the presences and absences of signs of ecosystem distress (such as the composition of exotic species or reduction in primary productivity), and by directly measuring resilience or capacity. His ecosystem health metaphor suggests a holistic approach to ecosystem function and the use of reliable indicators (Rapport 1995).

Indicators and statistical techniques are often used to identify activities that degrade ecosystem services, and relationships between these biotic and abiotic stressors. Indicator taxa are species whose density, presences or absences, or infant survivorship are used as measures of ecosystem conditions or can be predicted by the present conditions (Hilty and Merenlender 2000).

Past studies have shown a positive relationship between high densities of small mammals and superior habitat quality (Krohne and Hoch 1999; Carey and Harrington 2001). As small mammal communities are affected by forest fragmentation, it is likely that they can serve as potential indicators of “forest health.” Holland and Bennett (2009) found that vegetation characteristics were important predictors of occurrence across ground-dwelling mammal species in forest fragments and more specifically, Carey and Harrington (2001) describe that presence was driven by forest-floor characteristics such as large coarse woody debris, understory vegetation and overstory composition.

Urbanized areas have continued to support small mammal communities. This may be due to reduced native predators and competitors unable adapt to urban conditions. As small mammals are able to thrive in these fragments, they have potential to be ideal indicators of the forest health of these patches (Nupp and Swihart 1998; 2000; Mossman and Waser 2001).

In this research it was our goal to assess small mammal biodiversity and its relation to forest fragment health. We collaborated directly with Forest Fragments in Managed Ecosystems (FRAME) project which baseline ecological data on over twenty-one local forest fragments has been collected. The purpose of the FRAME

project is to better understand the ecological interactions in forest fragments within urban and suburban environments. To reach our goal we completed three main objectives (1) use non-invasive track tubes to inventory small mammal biodiversity in 10 forest fragments in northeastern Delaware, (2) develop a potential metric of forest health using FRAME data and (3) assess if small mammals can be used as potential indicators of forest health by comparing our measured biodiversity from objective 1 to our forest health metric from objective 2.

STUDY AREA

We sampled in ten forest fragments ranging in size from 2.6 ha to 16.3 ha and located throughout Newark, DE. We placed tubes at pre-defined points used in the FRAME project amongst 10 of their 21 sites (forest fragments) that are designated as Christiana Creek 1, Coverdale, Dorothy Miller, Ecology Woods, Folk, Glasgow II, Laird, Reservoir Hill, Webb Farm, and White Clay II (CC1, CD, DM, EW, FO, GG2, LA, RH, WF, and WC2 respectively; Figure 1).

METHODS

As part of the FRAME project, each site has been sampled at intersections of a 25m grid, except the University of Delaware's Ecology Woods which was gridded previously at 50 m intervals. We chose 10 points from these previously sampled grids at which to place our track tubes. At each chosen point within each site, soil samples and various vegetation parameters had been previously collected by the FRAME project. We sampled each randomly selected grid point within our ten sites during the second week of August, 2012. To capture small mammal presence we used track tubes

made of plastic rain gutter cut into 12” lengths and taped together to form a cylinder. We adapted the tube design from Drennan et al. 1998 and Glennon et. al 2002, with slight modifications due to disturbances from raccoons. At either end of the tube we placed small felt pads soaked with a mixture of carbon black and mineral oil. Between the felt pads we placed Rite in the Rain paper to record footprints of small mammals traversing the tube. We used a smear of peanut butter in the middle of the tube to attract small mammals. Two tubes were placed at each of the 10 selected points in each of the 10 sites for a total of 20 tubes per site. We left tubes out for 24 hours. Upon collection we removed the track sheets from each tube and put clear contact paper over the track sheet so it could be preserved. For every tube, we recorded if there was raccoon interference, occurrence of small mammals or if there were too many raccoon markings to tell if there was small mammal occurrence. For the tubes that did show small mammal occurrence, we identified how many different species were present based on visible tracks. We used Elbroch’s *Mammal Tracks & Sign: A Guide to North American Species* as a guide to the tracks. Logistical constraints limited us to a single replicate at each site.

We used a Principal Components Analysis (PCA) to describe forest structure using data collected by the FRAME project. Variables included in the PCA were average density of vegetation, soil pH, percent coarse wood debris, total snail weight from litter samples, soil calcium:aluminum ratio, average basal area, average tree diameter at breast height (DBH), percent ground cover, percent multi-flora rose cover, percent non-native cover, total stems and percentage non-native stems. We then used

linear regression to assess a cause and effect relationship between our first Principal Component and our measure of species biodiversity.

RESULTS

Of the 200 total tubes, 67 had evidence of small mammal presence. The number of tubes with small mammal signs ranged from 0-15 across sites (Table 1). We were not able to identify tracks to species due to indistinguishable track sheets, though we were able to discriminate how many different species were present per site. The number of different species of small mammals ranged from 0-4 across sites (Table 2). The Principal Component Analysis identified five significant gradients that explained 69.3% of the variation in our dataset. We focused on PC1, which accounted for 30% of the global variation in our dataset (Figure 2). Coarse woody debris, DBH, and basal area all had positive loadings on this gradient while various metrics of non-native species or early successional stages loaded negatively. When we regressed the number of different small mammal species against the PCA results we saw a significant cause and effect relationship with an increase in PC1 relating to an increase in small mammal biodiversity ($R^2 = 0.5956$; $p = 0.009$), demonstrated in Figure 3.

DISCUSSION

The Principal Components Analysis identified that a gradient of invasive species and succession accounted for a significant amount of our habitat variance amongst sites. Although it is open to interpretation we suggest that this gradient is a plausible metric for forest health, with fragments at the lower end of the gradient exhibiting a higher amount of non-native species, and fragments at the high end of the gradient being more mature and containing woody debris. Our index of small mammal

biodiversity regressed significantly with this gradient suggesting a positive relationship between small mammal biodiversity increased DBH, coarse woody debris, and Basal Area, and a negative relationship with non-natives and early successional indicators. Holland and Bennett (2009) found that vegetation characteristics were important predictors of occurrence across ground-dwelling mammal species in forest fragments. More specifically, presence was driven by forest-floor characteristics such as large coarse woody debris, understory vegetation and overstory composition (Carey and Harrington 2001). This is expected as small mammals can use CWD and understory vegetation for traveling, foraging and nesting (Mills 1995; Bowman et al. 2000). For example, *Peromyscus*, are considered generalists, occupying a variety of habitats, though *Peromyscus* species tend to favor areas with relatively high density of shrub-understory vegetation. *Peromyscus* have colonized and maintained high densities in patches where plant succession has progressed towards a woody-species dominated community (Smith and Speller 1970; M'Closkey 1975; Schweiger 2000; Lee 2004). It is also thought that CWD provides increased food resources protection from avian and mammalian predators which may also contribute to higher levels of biodiversity in these areas (Carey and Johnson 1995; Carey and Harrington 2001; Meiners 2007).

Conversely, many other native small mammals are less tolerant to forest fragmentation than introduced species (Bennett 1990) and the introduction of invasive plant species may reduce rodent fitness (Bolger et al. 1997). So their increased presence in our forest fragments with fewer invasive also follows previous literature, although the literature focusing on the direct relationship between small mammals and non-native plant species is limited.

Other past studies have shown a positive relationship between high densities of small mammals and superior habitat quality, which emphasizes the importance of complex forest ecosystems and habitat heterogeneity to maintain diverse resilient mammal communities (Krohne and Hoch 1999; Carey and Harrington 2001). *Rosa multiflora*, a non-native found in high densities in many of our sites, tolerates a wide range of conditions, invades and displaces native vegetation, and threatens this ideal superior habitat quality. Again, our findings support this previously seen inverse relationship between small mammals and non-natives.

Ultimately our findings support the use of small mammal biodiversity as a potential indicator for forest health. This is important as measuring small mammal biodiversity using track tubes is a relatively inexpensive method compared to live trapping, it is non-invasive, repeatable, and limits exposure to potential zoonotic diseases. However, we suggest future research is needed in the region further elucidate the underlying process. If that process is well defined then using track tubes to measure small mammal biodiversity could be implemented as a long term monitoring strategy in the forest fragments of the mid-Atlantic.

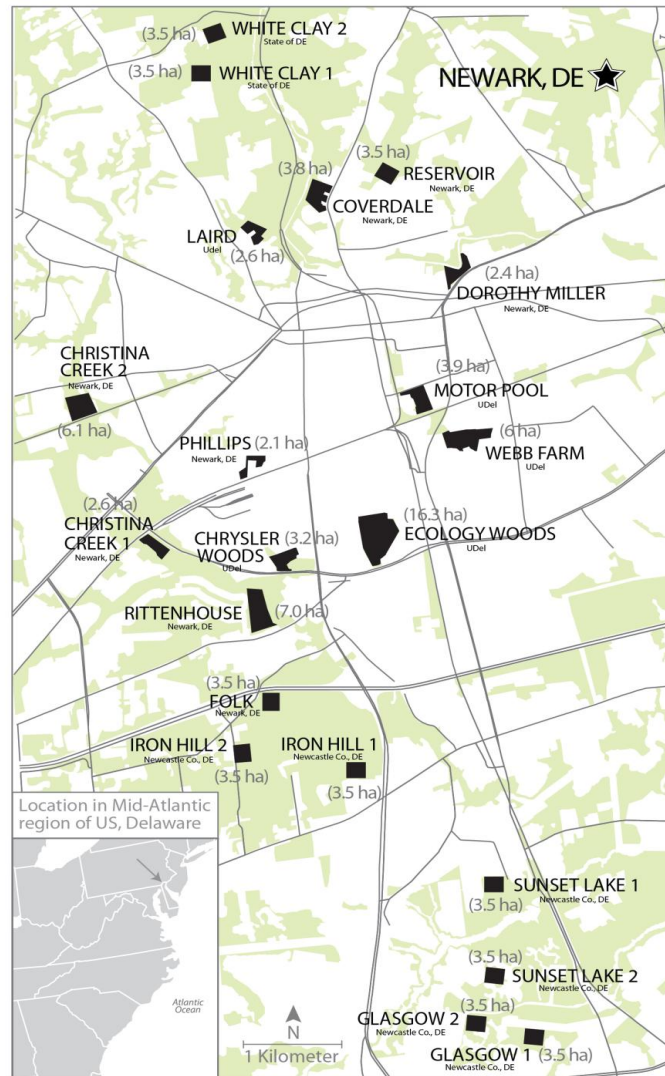


Figure 1 A map of the FRAME sites throughout Newark, DE. Of the 21 sites, 10 were used in this study.

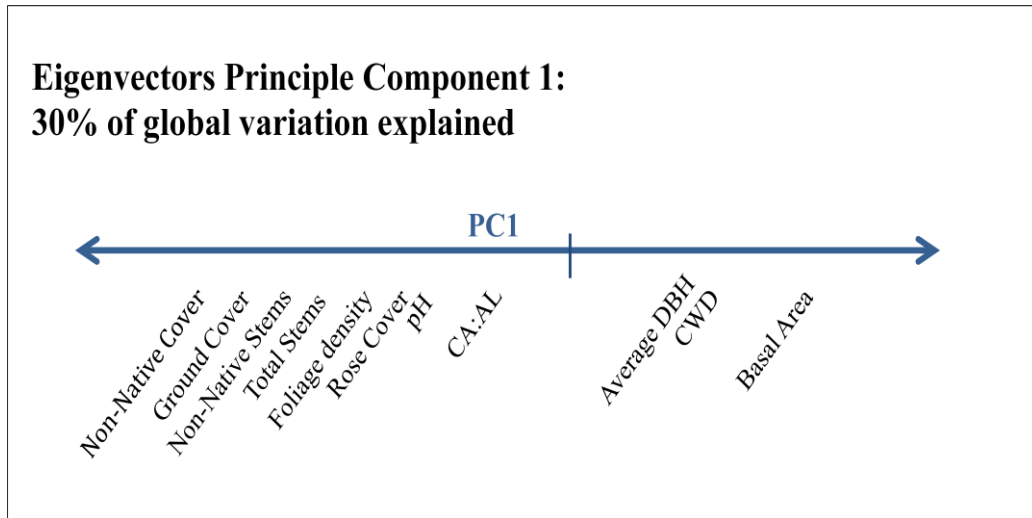


Figure 2 PC1, which accounted for 30% of the global variation in our dataset

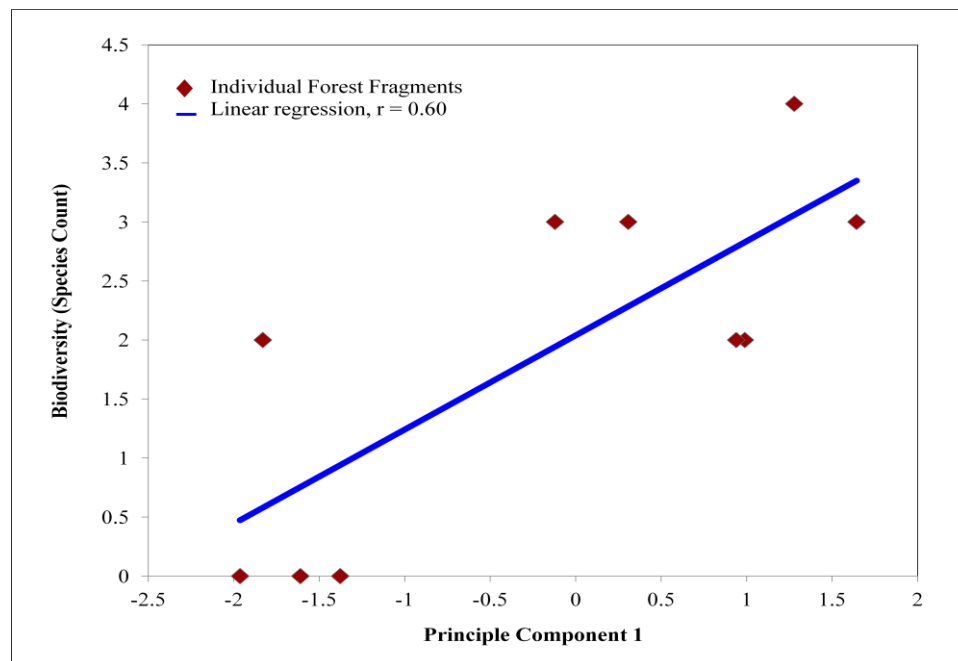


Figure 3 Number of different small mammal species per site regressed against the PC1 results

Table 1 Tubes with evidence of small mammal presence per site

Site	# of tubes with small mammals tracks
CC1	0
CD	0
DM	9
EW	10
FO	15
GG2	14
LA	0
RH	3
WF	3
WC2	13

Table 2 Number of different species present per site

Site	# different species per site
CC1	0
CD	0
DM	3
EW	3
FO	4
GG2	3
LA	0
RH	2
WF	2
WC2	2

Chapter 2

MODIFYING TRACK TUBES FOR USE IN AREAS WITH HIGH RACCOON DENSITIES

INTRODUCTION

Measuring the abundance, distribution, and species richness of mammals is essential to studying populations, community ecology, and establishing conservation priorities. Although not an exhaustive list some techniques that are used to take such measurements include, counting of dung, nests, trails, calls or tracks, direct observation along transects, photographic capture with camera traps, and live capture. (Murray 1957; O'Farrell et al. 1994; Karanth 1995; Fashing and Cords 2000; Jennelle et al. 2002; Silveira et al. 2003).

Direct observation or line transect techniques are only applicable to larger species which are easier to spot or leave a more apparent sign, can be biased towards diurnal species, and are highly dependent on favorable field conditions (Silveira et al. 2003). Live traps are expensive, require extensive effort and invasive animal handling (Glennon et al. 2002). Camera traps involve high initial costs, though this method is often considered the most appropriate for mammal inventory for many environmental conditions. This is an effective technique to provide a useful index of animal abundance, particularly for animals that cannot be individually recognized from their markings where an estimate or count is possible. However this method has been considered inappropriate for capturing images of smaller species (Carbone et al. 2001;

Yasuda 2004). Mark-recapture estimates are effective for small mammal populations, and in providing insight regarding individual characteristic such as sex, age and condition. However when one is simply estimating relative abundance, this method can be labor intensive (Nichols and Pollock 1983; Wiewel et al. 2007) and is inherently invasive.

Non-invasive track tubes provide an inexpensive method to identify composition and relative abundance of small-mammal species. Track tubes record footprints left on a surface such as contact paper inside the tubes, enabling researchers to identify presence as well as an index of abundance (Drennan et al. 1998; Glennon et. al 2002). Given their ease of use and low costs, track tubes provide an efficient way to complete large scale sampling in a short amount of time and eliminate risks that come with the handling of animals (Boonstra et al. 1992; Quay et al. 1993; Drennan et al. 1998; MaBee 1998; Wiewel et. al 2007). Studies comparing the effectiveness of track tubes to traditional live trapping techniques show that track tubes recorded the same species and that estimates of relative abundance were similar to those calculated from live trapping. It should also be noted that there was difficulty in distinguishing between species that were extremely morphologically similar with both techniques (Glennon 2002).

Here we provide an update and insight into a modification of track tube design for areas with high raccoon densities. Although Drennan et al. (1998) and Glennon et al. (2002) were successful in using track tubes to measure small mammal biodiversity; we initially encountered problems using their described methods in our study area. We found that the majority of our track tubes were interfered with by raccoons, making measurements of our target small mammal species nearly impossible. We describe a

modified track tube design that can be effective in areas with high densities of *Procyon lotor*.

STUDY AREA

Our study was conducted in 13 forest fragments of Newark Delaware. These fragments range in size from 2.1 ha-16.3 ha; some are surrounded by agricultural landscape, while others are in closer proximity to residential areas. Assessments were completed during the months of July, August, and September of 2012.

Methods

Test Trial

We cut our first tubes out of 12 inch lengths of aluminum gutter pipe, with a width of 4 inches and a height of 2 inches. We attached a 12 inch strip of plexi-glass inside the pipe with velcro and glued a 2 inch dish made of split PVC pipe in the middle to serve as a feeding dish. We sprayed a mixture of chalk powder and denatured alcohol on to the ends of the plexi-glass and attached contact paper between the chalk and the feeding tray to capture tracks (Orloff et al. 1993; Drennan et al. 1998). We tested these tubes in the backyard, of the Newark residential area and found that the chalk failed to be water resistant and the dimensions of the gutter seemed to restrict which small mammals were able to enter the tube. This led us to modify the design before a more formalized assessment undertaken.

Trial #1

Following methods described by Drennan et al. 1998, Glennon et. al. 2002 and Wiewel et. al. 2007, we used two 12 inch lengths of plastic rain gutter attached along

one side with duct tape. The U-shaped gutter lengths were 4 inches wide and 2.25 inches high. The edge not taped together, was then held together with two binder clips, creating a tube that was 4 inches wide and 4.5 inches high. A plexiglass track plate was attached by Velcro along the bottom of the tube to create a flat, smooth surface for track capture. Felt squares were placed at both ends of the track plate, serving as ink pads. Instead of chalk powder, we mixed carbon black and mineral oil in a 1:3 ratio to serve as our ink, limiting the impact of precipitation. We again used contact paper to capture tracks and used approximately 1 tablespoon of peanut butter as bait. Tubes were left out for approximately 72h. Within each of the 13 forest fragments, 10 points were randomly selected and one tube was placed at each point. Many of these traps (73.84%) were found opened, some missing the plexi-glass structure entirely. The track pads that were not harmed had a lot of small mammal traffic, making identification of individual tracks nearly impossible.

Trial #2

To address the above issues, we made several modifications to our tube design. Instead of using binder clips to keep the tubes together, we permanently sealed them with duct tape. We also permanently glued the plexi-glass (which had the feeding dish, felt pads with ink, and track paper) directly to the rain gutter with glue. Instead of using contact paper to record the tracks, we used Rite in the Rain paper, which seemed to pick up tracks clearer and was also more durable during inclement weather. We changed the ratio of carbon black to mineral oil to 1:1.5 so that the ink pads transferred ink better and that tracks were recorded with more clarity. We put less bait in each tube to reduce the chance of attracting larger mammals and limit the amount of

overall foot traffic, and put bait at the top of the tube, hanging from a fixture, to encourage animals to stand on their hind legs, in the hope that we would get a more complete footprint. We limited our number of sampled sites to 10 with this method due to logistical constraints, but put two tubes down at each of the 10 random points within each site (rather than one tube per point). To further reduce traffic, we reduced the amount of time that tubes were left out to 24 hours.

Following second large scale trial we continued to make minor modifications to the tube design to improve future potential applications. We tested different types of bait and/or using no bait to improve track capture, and different tube lengths to further limit raccoon interference. We complete these sub-trials were only repeated in Ecology Woods, an area with known raccoon and small mammals from the previous trials.

Different Types of Bait

We tested different types of bait including, peanut butter; peanut butter on bread; peanut butter on a crouton; and peanut butter on a peanut. This was to see if small mammals were less likely to spend a long time in the tube if bait was easily handled, creating a confusion of tracks. We did four trials of each treatment, with the treatments being randomly assigned. Trials were completed in Ecology Woods, and tubes were left out for 24 hours.

Bait vs. No Bait

We also tested the role of bait to see if not using bait could potentially further deter larger mammals, while still attracting small mammals since they have a proclivity for travelling under cover when possible. We ran trials with the modified tubes, putting bait in half of these, and the other half without bait. These trials were done in Ecology Woods, one of our original forest fragment sites. A total of 40 tubes were put out, half with bait, and the other half without bait, and tubes were left out for 24 hours.

Raccoon Proof Tubes

We also made two sets of tubes: one that was 24 inches in length and the other 36 inches in length. The plexi-glass structure was placed directly in the middle, with an extra 6 inches of tube on each side of the ink-pad for the first set, and an extra 12 inches extra tube on each side for the second set. We made 40 tubes that were 24 inches in length and 40 tubes that were 36 inches in length. The purpose of extending the size of the tube was to prevent raccoons from reaching the ink pad and smudging the paper even if they were attracted to the tubes. These tubes were baited with peanut butter and placed in ecology woods in for 24 hours.

RESULTS

Trial #1

From our first assessment, many of our traps were found opened, several were also missing the plexi-glass structure. The tracks that were not harmed had a lot of foot traffic, making identification of individual tracks nearly impossible (Figure 4). During our first assessment, 34 of 130 tubes were not damaged and 96 out of 130

experienced interferences with raccoons (25.15% and 73.85% respectively). Since we were not able to identify any tracks, we recorded whether tubes experienced raccoon occurrence or not.

Trial #2

Our second assessment was much more successful than our first, although we still had issues with raccoons as they were able to reach their paws into the tube and smudge tracks on paper. Forty-one percent of our tubes had tracks that were clear enough for identification and sheets looked like those in Figure 5. For this set we were able to record which tubes experienced raccoon occurrence, which tubes had small mammals, and how many different small mammal species were present.

Different types of bait

All four of our bait treatments experienced small mammal presence. We recorded what percentage of the tubes has small mammal presence and ranked the clarity of these tracks. Seventy-five percent of the tubes with Peanut butter on bread were used by small mammals, and had the clearest tracks. With peanut butter alone 75% of the tubes had tracks, and tracks were ranked second in terms of clarity. Small mammals entered half of the tubes with peanut butter on a peanut and this treatment was ranked third in terms of clarity. In tubes with peanut butter on a crouton we saw 50% had small mammal tracks and that they had the least clear tracks (Table 3).

Bait vs. No Bait

Of the 24 baited tubes, 52.5% had noticeable tracks and 47.5% did not have tracks. Of the 24 tubes without bait, 45% had tracks and 55% did not have tracks.

There were three different species identified in the tubes with bait and two different species identified in the tubes without bait.

Raccoon Proof Tubes

We had 100% success rates with the tubes that were 24 inches and 36 inches. We defined a successful trial as not having any kind of markings that would interfere with the identification of small mammal tracks. Raccoons appeared unable to reach far enough into the tube to encounter the ink pad and touch the track paper.

DISCUSSION

Track tubes provide a relatively rapid, cost effective method to record presence of species of small mammals. Track tubes are comparatively inexpensive, costing less than \$3.00 per track tube, while live traps cost \$8.00 or more, depending on what type of trap you purchase. This is also a less invasive way to survey small mammal populations as no handling is involved, thus there is also limited need for permits.

Although there are limitations to track tubes (individual animals cannot be distinguished by footprint characteristics, lack of data on sex, age, reproductive condition, and other morphological characteristics) they are effective for assessing presence, absence, and relative abundance between sites (Glennon et al. 2002). This study did not compare capture rates with that of live traps, although prior studies show that small mammals are detected equally by track tubes and live captures (Drennan et al. 1998; Glennon et al. 2002).

This paper provides a means of efficiently using track tubes in areas with high raccoon densities, which is important for small mammal assessments taking place in areas such as the Mid-Atlantic. We experimented with a variety of different

modifications, with the intention of determining a technique that would provide water resistant, legible track sheets for identification. From these trials, we found out that tubes should be left out for no more than 24 hours to reduce foot traffic. We also learned that bait may not be as important as previously thought, and this may also be another effective way to limit foot traffic. In terms of different types of bait, peanut butter on bread provided the clearest tracks, though all four treatments received some level of small mammal occurrence. Rite in the Rain paper was more effective than contact paper for recording tracks, especially during inclement weather. Particularly in areas with high raccoon densities, using tubes that are 24 inches long will prevent them from disturbing track sheets.

More studies are necessary to further explore these adjustments as completing more than a limited amount of test trials was beyond the scope of this study.

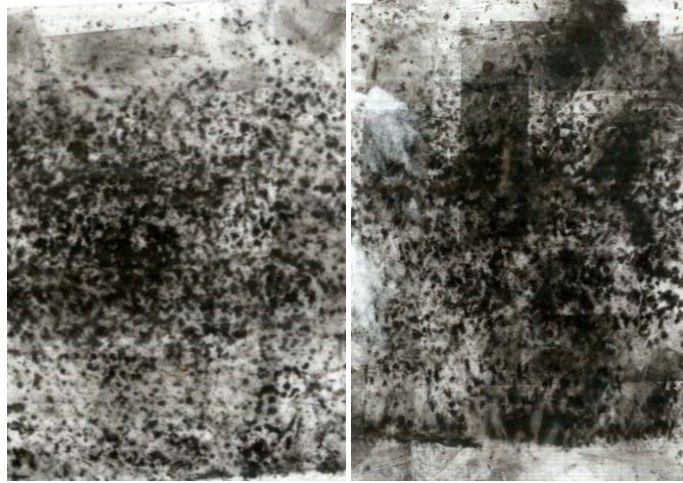


Figure 4 Track sheets from Trial #1

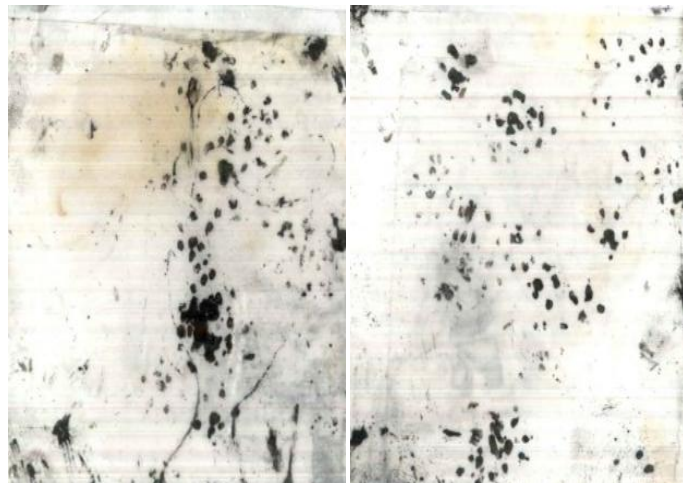


Figure 5 Track sheets from Trial #2

Table 3 Results from different types of bait trial

Bait	Tracks Captured	Clarity (ranked)
Peanut Butter	75%	1
Peanut Butter on Bread	75%	2
Peanut Butter on Peanut	50%	4
Peanut Butter on Crouton	50%	3

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