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Digital Object Identifier: <https://doi.org/10.13023/etd.2021.036>

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VOLE POPULATION DYNAMICS IN COVER CROPS TRANSITIONING TO SOYBEANS
WITH INTEGRATED PEST MANAGEMENT BY HABITAT MODIFICATION

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in
Forest and Natural Resource Sciences in the
College of Agriculture, Food and Environment
at the University of Kentucky

By

Jena L. Nierman

Lexington, Kentucky

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Management

Lexington, Kentucky

2021

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ABSTRACT OF THESIS

VOLE POPULATION DYNAMICS IN COVER CROPS TRANSITIONING TO SOYBEANS WITH INTEGRATED PEST MANAGEMENT BY HABITAT MODIFICATION

The use of cover crops has been a widely used method in rotational row crop production. Cover crops have minimized soil runoff and aided in maintaining nutrients in agricultural fields. Increased use of cover crops has seen a corresponding increase in the amount of damage done to soybeans by voles. Currently, there are no mitigation methods that successfully decrease vole populations in agricultural fields. The use of habitat manipulation as an integrated pest management solution has not been studied as a practical solution for vole population management. During 2019 and 2020, I tested the impacts of various cover crop termination timings as an integrated pest management solution for decreasing population of voles and small mammals in cover crop fields transitioning to soybean. I used a Pollock's Robust Design Model and a generalized linear model to determine impacts of cover crop termination treatments and time covariates on Total Number of Individuals (TNI) in plots, survival rates, and emigration rates. Treatments consisted of removing cover crop 4 weeks, 2 weeks, and one day prior to planting soybeans. Overall, survival rates for small mammals ranged from 50%-90% and followed a similar decreasing trend after termination of cover crops. The analysis of TNI for small mammals and voles both showed that treatment impacted their numbers and followed the trend of decreasing or leveling of populations after cover crop termination. Overall, I found support for cover crop termination timing as an integrated pest management for small mammal population control technique however this may not be enough to drastically reduce vole damage to soybean plants at the locations of colonies. Investigating if this method combined with other mitigation methods like raptor perches may provide a more efficient solution for farmers seeking to manage voles and other small mammal populations.

KEYWORDS: Voles, Soybeans, Cover-crops, Agriculture, Integrated Pest Management

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3/29/2021

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VOLE POPULATION DYNAMICS IN COVER CROPS TRANSITIONING TO SOYBEANS
WITH INTEGRATED PEST MANAGEMENT BY HABITAT MODIFICATION

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DEDICATION

To my family who has always supported me and encouraged me to take my own path.

ACKNOWLEDGMENTS

Thank you to our funding sources, the Kentucky Soybean Board and Natural Resource Conservation Service via a Kentucky Conservation Innovation Grant. I would like to thank my thesis committee Drs. Matt Springer, John Cox, and Steven Price for all their help. Thanks to all the farmers who cooperated with us on this project, and to David Brandon who helped me locate all my field sites. For help in the field I thank, Jennifer Runnings, Beth Evers, Wendy Leuenberger, Keely Kohen, Allison Davis, Jordan Winkenbach, and Joey Zigler.

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CHAPTER 1. Vole Population Dynamics in Cover Crops Transitioning to Soybeans with Integrated Pest Management by Habitat Modification

INTRODUCTION

Members of the order Rodentia are a unique group of individuals, having high birth rates, cyclic populations, and typically are small in size. Numerically, small mammals dominate the class Mammalia and are characterized by weights of 5 kg or less. Small mammals are prolific breeders when conditions are favorable, follow the r selection of the r-K selection continuum, exhibit short generation times, high rates of dispersal, high fecundity, and populations overshoot K cycle (MacArthur & Wilson, 1967, Pianka, 1970, Stoddart, 2012, Tripathi, 2014). They have adapted and evolved to live in a wide variety of ecological niches (Stoddart, 2012). Voles (i.e., *Microtus* spp.) and lemmings are the most commonly known species for cyclic populations whereas mice species (i.e., *Peromyscus leucopus*, *Peromyscus maniculatus*) are less likely to do so. Given this, microtine rodents will reach high localized densities every three to four years (Krebs, 1970, Vessey & Vessey, 2007, Witmer et al., 2007). It is not yet known what is exactly driving cycles in vole populations (Krebs, 1996).

Multiple theories have been proposed on why microtines have cyclic populations. Krebs and Myers (1974) theorized four questions when it comes to studying fluctuations in cyclic populations: what prevents an unlimited increase in the population: why is the cycle 3-4 years; how do the populations sync over a large area; and finally, what determines the amplitude of the fluctuation? Christian (1950) suggested that as the number of voles increases, their crowding produces stress, which triggers the adreno-pituitary system to work until exhaustion. When paired up with severe climatic conditions and the obligation to breed in the spring, the stress-induced exhaustion could cause a decline in mammals with a cyclic population. Advances in genetics have allowed a deeper understanding into complex social structures of microtines, which was theorized to also contribute to the changing of population cycles (Ford 1975). Today, three paradigms are thought to influence cyclic populations: the food paradigm, predator paradigm, and the social paradigm (Krebs, 1999). The food paradigm requires that both food quantity and the quality

regulate rodent population density, and population outbreaks or decreases are caused by changes in food supply (Krebs, 1999). The predator paradigm states that mortality caused by predation can regulate populations. This occurs, if the average density of populations is below the limit set by food, and the outbreaks of rodents are caused by natural or artificial predator control activities (Krebs, 1999). The social paradigm describes the impact of social interactions between individuals, which leads to changes in physiology and behavior, and ultimately reduces births and increases death (Krebs, 1999). Despite multiple studies in all three paradigms (Krebs, 1999), the question is still undetermined and most likely related to multiple factors (Krebs, 1999, Korpimäki et al., 2004).

Ecosystems can be driven by the presences of small mammals. Short generation times and sensitivity to alterations in ecosystem functions, small mammals make excellent ecosystem health indicators. Small mammals have been shown to be key components of ecosystems, which can be altered by their presence or absence. They can shift the plant diversity and species composition, plant chemistry, and productivity of the plant community (Olofsson et al., 2013, Moorhead et al., 2017, Poe et al., 2019). When there is a lack of small mammals, plant species richness is lowered while above-ground plant biomass increases (Poe et al., 2019). Small mammals can lower plant productivity while promoting plant richness, leading to a decrease in plant species diversity in temperate grassland plant communities (Poe et al., 2019). Invertebrate herbivores can also be mediated by small mammals on different landscapes (Poe et al., 2019).

In agricultural fields, small mammals can contribute to predation services like weed seed predation or disservices such as crop damage through the consumption of crop seeds or plants which may outweigh the services provided (Tshumi et al. 2018). These impacts either positive or negative may be situationally specific. In the Netherlands, mice consumed between 33%- 88% of weed seeds in cereal fields, providing a greater service than invertebrate species who consume only 3%-38% of weed seeds (Westerman et al., 2003). When crop seeds being consumed, the timing of their consumption can be important as it may change its characterization as a service or disservice. For instance, in the Midwest, *Peromyscus* spp. consume weed seeds and waste grain in agricultural fields (Berl et al., 2017). If consumption of planted crop seeds or plants is preharvest then it could be negatively impacting yields, however if the seeds for the same plant are consumed after

harvest (i.e., waste grain) it is beneficial in removing competition for plants during the following growing season (Tschumi et al., 2018). Higher consumption of weed seeds can be a management strategy implemented by farmers to lower weed emergence in agricultural fields. However, having high populations of small mammals may lead to more crop predation if weed seed availability does not meet population demands (Fischer et al., 2018).

Agricultural field location and farming practices can be important to the occurrence of foraging behaviors and diet. For example, if a crop field is adjacent to a forest edge, it is more likely to have seed predation on both weed and crop seeds (Abercrombie et al., 2017). Farming practices also impact small mammal behavior and populations. No-till fields typically have a higher density of small mammals or vole burrows when compared to tilled fields (Jug et al., 2008, Heroldová et al., 2018). Resulting in seed predation being significantly higher in no-till agricultural systems verse traditional tillage practices (Brust & House, 1988)

Small Mammals in Agriculture

Agricultural ecosystems have had severe impacts on the earth but with the development of no-till farming and the use of cover crops, farmers have lessened the negative impacts. Generally, agricultural ecosystems provide humans with food, forage, bioenergy, and pharmaceuticals. When not appropriately managed, agricultural ecosystems can have a negative impact on the environment through sedimentation of waterways, loss of soil from fields, nutrient runoff, greenhouse gas emissions, loss of wildlife habitat, and pesticide/herbicide poisoning of non-target species (Power, 2010). Agricultural ecosystems often require different conservation methods to keep nutrients and soil in the field. Soil runoff, pesticide runoff, and nutrient loss can be reduced by keeping the soil intact during non-production periods, commonly referred to as no-till (Swinton et al., 2007). The addition of cover crops to this system adds another layer of conservation benefit. Cover crops are grasses or legumes planted in between the cash crop season (Reicosky & Forcella, 1998). Cover crops aid in the carbon cycle, nutrient cycling, wildlife habitat benefits, and select cover crops can reduce the number of chemicals for weed control (Reicosky & Forcella, 1998, Wilcoxon et al., 2018, Prieur & Swihart, 2020).

With a decline in prairie systems throughout North America, small mammals were forced to reside in places such as agricultural fields (Samson & Knopf, 1994, Ceballos et al., 2010). Small mammals increase in abundance, species richness, and diversity in complex agricultural ecosystems (Alain et al., 2006, Fischer et al., 2011). Specifically, more vegetation cover within fields increases rodent abundance and species richness (Fischer & Schröder, 2014). Thus, finding a significant positive relationship between vegetation cover, species richness, abundance, and species diversity is sensible (Olson and Brewer, 2003). Habitats that are un-mowed such as field edges or habitat strips, will also support higher densities of small mammals (Lin & Batzli, 2001, Aschwanden et al., 2007). However, disturbances such as plowing can have a negative impact on small mammal populations, especially voles (Jacob, 2003). The incorporation of cover crops can provide vegetation cover and dense vegetation, where small mammals like voles thrive in during times of the year when other foods and cover resources are lacking in the environment (Hines, 1993, Prieur & Swihart, 2020).

Voles utilize a variety of habitat but typically thrive in grassland areas. They are considered a semi-fossorial species and create elaborate burrowing systems. These burrows are significant to their daily routine and livelihood. Burrows will be used to raise the young, store food, and protect from weather and predators (Witmer & VerCauteren, 2001). Cover crops make prime habitat for voles as they provide high-quality food sources such as legumes, alfalfa, wheat, corn, tubers, and insects (Cole & Batzli, 1979, Hines, 1993). Higher quality food and foraging can influence the average and peak vole population densities positively. Some cover crops such as alfalfa, have increased the rates of growth, breeding, and production of young voles (Cole & Batzli, 1979, Jareño et al., 2015).

Agricultural fields are a consistently changing landscape, potentially altering survival rates as habitat changes. Throughout winter in the Midwest, it is estimated that *Peromyscus* Spp. have a 57-79% monthly survival rate in row crop production (Berl et al., 2017). When compared to *Peromyscus* Spp. in other habitats such as forested habitats, it is found that *Peromyscus* Spp. have a similar consistent rate of survival (Schorr et al., 2007, Linzey et al., 2012). Similar survival rates for *Peromyscus* Spp. could be the result of them being a generalist species (Pinkert et al., 2002, Schwer, 2011). However, when examining voles, we do not know their survival rates in a wide variety of habitats. In old pasture fields

containing a majority of bluegrass (*Poa pratensis*), monthly survival estimates in winter for voles ranged from 25% for males and 75% for females, increasing as the season progresses (Cole & Batzli, 1978). Densities of voles varied considerably between studies; in bluegrass fields, there can be a range of 25 – 90 individuals per hectare (Cole & Batzli, 1978, Getz et al., 2001). Survival for row crop productions has not been reported for actively producing agricultural fields in North America, and there is a substantial amount of information lacking on population dynamics of voles and some small mammals in these fields. This is a gap that my research will be able to fill.

Crop damage by wildlife is a common occurrence in all types of agricultural fields. In 2001, it was estimated that wildlife caused 619 million worth of damage across agriculture, personal properties, and other industries (USDA, 2001). Corn, wheat, soybeans, and many other types of crops can be affected by wildlife damage (Conover & Decker, 1991, Matthews, 2019). According to the United States Department of Agriculture (USDA, 2001), several wildlife species are identified as having the ability to cause significant amounts of agricultural damage, including deer, wild pigs, geese, and rodents (i.e., small mammals and rats).

Despite the benefits that small mammals can provide to agricultural ecosystems, they are normally seen as a pest or an unwanted species due to agricultural damage. Damage from small mammals can be broad in both scope and intensity to food and other cash crops (Yonas et al., 2010). It was estimated that mice alone reduce yields by 12.4% when their abundances are greater than 100 mice per ha⁻¹ (Brown et al., 2007). There has been an increase of vole damage throughout North America, which may be linked back to the rise of the no-till farming practice (Witmer et al., 2007). Voles will cause "eat-outs" in soybeans fields. An "eat-out" is an area where there is little or no crops remaining (Witmer et al., 2007). However, quantifying the amount of damage from voles has proven to be difficult due to inconsistencies in the damage done by voles (Prieur & Swihart, 2020). Unfortunately, even though our knowledge of small mammal population dynamics has improved greatly, the application of this knowledge to pest management has been limited (Krebs, 1999). Dealing with this damage requires different pest management strategies for population control and damage management (Baldwin, Salmon, Schmidt, & Timm, 2014).

Understanding how or why damage is occurring allows for these strategies to be developed and their efficiencies improved.

Controlling vole damage in agricultural fields can be difficult for producers for several reasons. Damage is seen in fields containing alfalfa, grains, sprouting corn, and soybeans (Witmer & VerCauteren, 2001). Many small-scale rodent control methods available for other circumstances (i.e., snap traps) do not translate well to the scale of row crop agricultural production systems. A combination baits of cholecalciferol plus diphacinone have been shown to successfully manage voles in artichoke fields (Baldwin et al., 2016). However, this method has yet to be tested in agricultural fields engaged in traditional row crop production (Baldwin et al., 2016). Zinc phosphide was re-examined and found to have a high uptake by voles when containing a lower concentration of zinc phosphide; however, this product is no longer eligible for row crop production (Jacob et al., 2010). In 1989, the U.S EPA banned the use of zinc phosphide bait for the use of rodent control in large-scale areas such as agricultural fields, removing a very effective rodent control method for larger-scale issues. Presently, there are no rodent control bait products available for use in agricultural fields in the U.S. allowing rodents such as voles to flourish in agricultural fields (Hines, 1993). Regardless of the effectiveness of rodenticides, they have limitations due to the countless findings on the negative impacts' rodenticides have on non-target species make it a subpar solution (Berny et al., 1997, Brakes & Smith, 2005).

Alternative methods to rodenticide have been examined and have their own limitations and side effects relating to the environment. Plowing can decrease vole populations by tilling through the habitat and destroying the burrows (Jug et al., 2008, Bonnet et al., 2013). In a comparison of tillage versus no-tillage systems, tillage systems had a lower number of voles (Heroldová et al., 2018). However, plowing the fields can make the fields susceptible to erosion, contribute to loss of moisture conservation, and increase tillage costs, whereas no-tillage management is more profitable (Hines, 1993, Heroldová et al., 2018). Snap trapping at large scales is an ineffective method for removing populations because they cannot remove the majority of the population due to the time and effort required (Krebs, Keller, & Tamarin, 1969). Witmer, Hakim, & Moser (2000) tried various experiments to see if they could deter voles from causing damage. In a lab setting, they created barriers around plants to prevent damage, but the voles could breach the

barriers by climbing or burrowing under. They also tried using an odor repellent, but they only showed to be successful at very high concentrations (Witmer, Hakim, & Moser, 2000). The lack of viable solutions for managing vole populations in large agricultural settings necessitates the creation of a viable solution.

Several studies have examined an integrated pest management (IPM) approach to small mammal issues in agriculture. IMP is defined as a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society, and the environment (Kogan, 1998). As previously mentioned, a handful of tested methods have shown promising results for mitigating vole damage but unfortunately, they are either not universally applicable or are only situationally successful and thus cannot be the only solution. Witmer et al. (2007) suggested actively managing the habitat that borders agricultural fields to lower the carrying capacity of rodents. Roadside areas along agricultural fields can provide suitable habitats where areas have been highly cultivated, and this is only true if the surrounding area is not a high-quality habitat (Galantinho et al., 2017). Vole populations can be impacted by roadside structures and crop coverage but specific impacts of this practice on populations are not well understood (de Redon et al., 2010). Natural predation has been a possible method to help mitigate vole populations and damage. Installing artificial perches can increase the predation pressure on voles during population outbreaks (Paz et al., 2013, Machar et al., 2017). Installed perches are more effective when the habitat has short vegetation compared to tall vegetation (Sheffield et al., 2001). Predation pressure from raptors on rodent populations is another method but cannot be relied on as the only solution (Sheffield et al., 2001, Machar et al., 2017).

One method that has not been heavily studied is the use of habitat manipulation within the crop fields themselves. In areas with high-quality food and habitat, populations of voles can reach greater peak densities (Cole & Batzli, 1979). To manage vole issues utilizing an IPM approach, Hines (1993) hypothesized habitat manipulation could limit vole populations and subsequent damages. Reducing or removing vole habitat, specifically the loss of cover and food, could force voles to leave the production fields (Hines, 1993). Manipulation of the habitat in no-till agricultural fields would require removing the dense

vegetation of the planted, cover crop. Cover crops provide voles with cover from predators and the natural elements while simultaneously providing a source of food (Sheffield et al., 2001, Prieur & Swihart, 2020). Cover crop removal could lower the carrying capacity of voles within an agricultural field as well as making them more vulnerable to predation (Witmer et al., 2009). Unfortunately, neither Hines, Witmer, nor anyone else has tested this hypothesis to provide insight into its potential as a control measure.

In Kentucky, farmers are concerned with the amount of damage that has been present in soybean fields. Creating a simple yet effective method for managing vole populations could be vital to successful crop production. I tested the effects of cover crop conversions on small mammal populations to better understand their ecological relationship. I hypothesized that termination timing of cover crops before planting soybeans could impact the survival and abundance of small mammals. If my hypothesis is supported, this could provide a tool for soybean producers to use when experiencing vole issues in their crop fields. Overall, this project will provide crucial information on the population dynamics of voles and other small mammals in row crop production fields, specifically soybeans, which is not previously known.

STUDY SITE

The study objectives were focused on the impact habitat change has on small mammal populations with an emphasis on voles; therefore, small mammals' occupancy specifically voles were confirmed before field site selection. I used a combination of landowner reports and scouting for signs of vole and small mammal activity to select farms with an extensive history of vole sightings or vole damage in Hardin County, Kentucky (see methods). The properties annually rotated the crops of corn (*Zea mays*), cover crops (*Secale cereal* or *Pisum sativum*), and soybeans (*Glycine max*). Field scouting took place January-February of 2019 and 2020 and 8 candidate agricultural fields of 75-200 acres on privately owned and operated farms were selected for study from 01 January- 28 June 2019 and 2020. The temperature during sampling ranged from -2.2 C° in winter to 32 C° in summer. Both sampling years had a wet planting season; Hardin county had a yearly average of 152 centimeters of rain, 25 centimeters higher than the normal average (National Weather Service, 2020). During the 2020 field season, from

March to June, there was an average of 11.4 centimeters of rainfall per month (National Weather Service, 2020). Agricultural field sites were a combination of 7 different soil types, listed from highest to lowest quantities were: Crider silt loam, Elk silt loam, Nolin silt loam, Lindside silt loam, Cumberland silt loam, and Ashton silt loam (USDA, 2019). During 2019, Hardin County, Kentucky harvested 39,000 acres of soybeans out of the 1,690,000 planted in Kentucky (USDA 2019).

METHODS

Scouting

I started by preliminary scouting farm fields with a history of vole damage to identify potential experimental fields this involved walking transects and searching for physical evidence of small mammals. Remnant corn crop stubble was used to guide the transects because they extended through the field in a straight and consistent manner, I would walk in one row and visually scan the ground of the row currently being walked in and the ground of 2-3 rows beside that row. The row was followed until the opposite end of the field was reached, then the process was repeated, going back 5 rows away from the initial row walked in. An average-sized field could take 2-3 days to scout efficiently. I investigated every sign of small mammals, determining whether it was vole or mice activity. Signs of vole activity included fresh scat, vegetative clippings, and runways leading to a colony (Hikes, 1995). A colony would consist of a series of burrow entrances and upturned soil with multiple runways leading to the location (Figure 1.1). Due to the lack of success in capturing voles most likely related to the inactivity of identified colonies found in 2019, I created an improved method for 2020 scouting. Determining the status of the colonies, active or abandoned, however, can be difficult. This led to the creation of a two-step approach to determine if a vole colony was active. First, if there was fresh scat or plant clippings by the entrance, the colony was characterized as active (Figure 1.1). If the colony status was still in question, pieces of vegetative matter were placed in an "X" formation over multiple entrances of the colony in question and checked the next day to see if they were removed. Unlike voles, during the first season I observed that signs of mice activity would often be a singular hole entrance into the ground, often hidden by weeds or corn stalks. Active colony locations latitude and longitude coordinates were recorded using a handheld Garmin RINO650t Global Positioning

System (Garmin Ltd., Schaffhausen, Switzerland) and loaded into ArcGIS (Esri, Redlands, California). In ArcGIS, 63.5 m × 63.5 m (1-acre) perfect square polygons were created to contain the maximum number of vole colonies. The squares represented the future placement of the trapping grids. I added a 50 m buffer around the edge of the grid to decrease the likelihood of catching species residing in edge habitat as well as to prevent small mammals from being caught in multiple grids. I then used the corner coordinates to recreate the grid at the field site (Romairone et al., 2018). I believe this buffer size was sufficient as I never captured an individual in a different grid than where they were originally captured.

Trapping

Each year of the study, I selected 4 of the 8 total field sites with active vole colonies that were also slated for conversion of cover crops into soybeans. Each field site contained a total of three trapping grids (A, B, C). The trapping grids were 63.5 m × 63.5 m creating a perfect square (1-acre). Within each trapping grid, there was a total of 85 Sherman traps (H.B 3" 3.5" 9" aluminum Sherman traps from H.B Sherman Trap Inc.), resulting in a total of 255 Sherman traps per field site. The grid layout could be described as a repeating pattern of a 5-side of a die (Figure 1.2) with the outer traps being 10 m apart and the center trap 7 m inward, an area which has been shown to be effective in covering the potential home ranges of small mammals in agricultural fields in the U.S. (Romairone et al., 2018). Trapping began in March, when temperatures allowed for safer thermal conditions (> 0° Celsius). Trapping followed a robust design schedule containing primary secondary trapping period. In 2019, I had a total of 3 primary periods. Each primary period consisted of 3 days of secondary trapping periods. In 2020, I had 6 primary periods with secondary trapping periods consisting of 3 days. In 2020, trapping increased by 3 primary periods due to a funding increase which facilitated our logistical abilities and efficiency. Each trap was baited nightly with a dime-sized mixture of peanut butter and rolled oats. Sherman traps were insulated with poly-fill polyester fiber when outdoor temperatures were expected to reach < 12° C. Traps would be opened at dusk the evening before a trapping day and checked no earlier than 30 minutes after first light, a schedule which approximates peak crepuscular activity periods of voles and mice

(Behney, 1936, Sabol et al., 2018). Due to the commonly high daytime temperatures present in late spring and early summer, traps were closed during the day.

Captured small mammals were marked with a uniquely identifiable pair of #1 size metal ear tags (National Band & Tag Company, Newport, Kentucky) and a passive integrated transponder (hereafter PIT Tag; Biomark APT 12 PIT tags, Boise, Idaho) injected subcutaneously between the scapulae. Each captured individual was scanned for PIT Tags using a Biomark's Global Pocket Reader Plus (GPR Plus, Boise, Idaho) in case ear tags were lost. Two types of markings are generally recommended to avoid double counting and increase the reliability of population estimates (Fokidis et al., 2006). I weighed individuals to the nearest gram by using a Pesola spring scale (PESOLA Präzisionswaagen AG, Schindellegi, Switzerland). I then identified the individual's sex, age, and species. Individuals that were <10g only received ear tags until they reached a greater body mass. For each individual, I measured the length of the foot, tail, and ear using a flexible plastic ruler. In 2019, *Peromyscus spp.* were grouped together. In 2020, *Peromyscus spp.* were not grouped together, using foot and tail measurements to aid in distinguishing between the two (Berl, 2017). Once processed, I would return each small mammal to the capture location. All trapping and animal methods were approved by the University of Kentucky IACUC (2020-3498).

Crop Vegetation (Habitat) Manipulation

I investigated the impact of crop vegetation change to soybeans on small mammal populations to assess its potential for alleviating depredation. To do so, I applied the herbicide mixture Roundup Power Max (The Scotts Company LLC, Marysville, Ohio) to remove cover crops within agricultural fields at different time periods before planting soybeans. This herbicide was the same normally used on these fields outside our experiment. I randomly assigned 1 of 3 different time periods for the herbicide to be applied to a grid within each field. Each grid letter represented a different timing of cover crop removal, right before planting (T0) was A, two weeks before planting (T2) was C, and four weeks before planting (T4) was B. The time periods for herbicide application were based on Hines (1993) suggested periods needed to cause voles to abandon a field; he recommended removing cover crops one month prior to planting soybeans,

eliminating both the food supply and protective cover from the voles. To determine if this timing was a sufficient, I wanted to have termination periods of one month, two weeks, and immediately before soybean planting. However, due to working on privately owned active farmland, time periods were also adjusted to minimize conflicts with the farmer's operation schedule (Table 1.1). In 2019, herbicide treatments were not applied to the study area because no voles were present within the grids. In 2020, due to concerns the farmers had for the weather, soybeans were planted after the first termination period in April. This was not anticipated or preplanned and is not following the regular planting season for soybeans in Kentucky which are typically planted around the beginning of May; however, this did not impact the timing of the herbicide treatments of my plots (Lee et al., 2007).

DATA ANALYSIS

I used the total number of individuals (hereafter TNI) to obtain estimates of small mammal abundance in 2019 and 2020. TNI is still heavily used today and recommended over estimating minimum known alive (MNA) because the latter creates a bias that has a greater number of individuals in the first and last secondary period compared to the middle secondary periods (Slade & Blair, 2000, Pocock et al., 2004, Fischer et al., 2011, Broughton et al., 2014). Since my data set was in count form, I applied a generalized linear model, specifically a Poisson regression in R (Alboukadel, 2021) to test for differences between the cover crop removal treatments and primary periods within the 2020 data set (Frome, 1983). I used a Poisson regression to account for the dependent variable being count data. I used a q-q plot and a residuals versus fits plot to confirm the data fit the Poisson regression assumptions. I first modeled the impacts of treatment and time for all the small mammal's species pooled together and then I exclusively examined the vole data to determine effectiveness of cover crop removal timing as a control measure. Because significance was present in both model outcomes, I used a complete estimated marginal means (EMM) post-hoc test to determine pairwise differences (Harvey, 1982).

I used Pollock's Robust Design model (Pollock, 1982) to analyze capture data. A Robust Design follows certain assumption to estimate parameters that include: (1.) Each

animal in the population has the same likelihood of being caught. (2.) The population is considered closed over the secondary sampling periods within a primary period. (3.) Temporary emigration is assumed to be random, Markovian, or based on a temporary response to the first capture. (4.) Survival rate is assumed the same for animals in the population (Pollock, 1982, Kendall, 2001). Robust design models are often ideal for small mammal data analysis due to the way capture-recapture data is collected because it can provide a less biased and more efficient estimate of population dynamic parameters such as survival (S), capture probability (p), recapture probability (c) and temporary emigration (γ) (Kendall, 2001).

In my robust design model, I assumed p and c within each primary period to be constant. Following the robust design, capture data in 2019 were sorted into 3 primary periods, with 3 secondary periods occurring within the primary periods, creating a total of 2295 trap nights per field (Table 1.2). In 2020, I sorted the trapping periods into 6 primary periods with 3 secondary periods occurring within the primary periods, giving a total of 4590 trap nights per field site (Table 1.3). In 2019, I tested survival and capture probability incorporating sex, species, site, and a combination of grid and site as covariates (Table 1.4). Data collected in 2019 allowed me to estimate small mammal population parameters during a "typical" rotation of cover crops to soybeans without the treatments applied in 2020. I analyzed 30 models for apparent survival (S), 30 models for probability of capture (p), and 3 models for emigration and immigration (γ) for the first phase of model selection (Table 1.5). The second model selection phase yielded 6 possible model candidates (Table 1.6). Overall, 2 models were supported with a Δ AIC score of ≤ 10 (Table 1.7). In 2020, I tested for the same covariates but made grid an independent covariate to account for the different herbicide treatments. Due to infrequent captures and no recaptures, *B. brevicauda* was removed from the data set. I conducted robust design analysis in R (R Core Team, 2017) utilizing the RMark package (Laake, 2013). Model selection was accomplished using the Akaike information criterion (AICc) and the Δ AIC. Due to the large number of potential models, I used a sequential workflow that creates subsets of models to fit models within and among candidate sets. Population parameters were not taken from robust design due to chances of estimation bias from temporary emigration rates (Cooch & White 2016). First, creating secondary candidate

model set from each parameter (S, p, γ) and then selecting covariates to carry forward to final candidate sets based on $\Delta AIC \leq 10$, giving a more accurate model selection with covariates (Morin, 2020). This is a combination of the normal comparison outlined by Burnham & Anderson (2002) and methods found in Morin et al. (2020). Focusing on one parameter at a time, I modified single covariates and a combination of covariates while the other parameters remained in their most complex form (Global model). I created a competing model list for each parameter in the models. The first phase of model selection had 38 models for apparent survival (S), 50 models for probability of capture (p), and 3 models for emigration and immigration (γ). The top parameter selected models are then combined and analyzed. The top parameter selected models resulted in 304 models. From the top parameter models, the final model candidate set was created. 2020, resulted a total yield of 8 final candidate top models (Table 1.8). The final top models were selected using likelihood of $(\exp [-0.5 \times \Delta AICc])$ (Burnham & Anderson, 2002). Once models were selected, I used model averaging predictions from RMark to obtain apparent survival and apparent capture probabilities (Laake, J.L. ,2013). Figures were produced using package ggplot 2 (Wickham, 2009).

RESULTS

In 2019, I marked a total of 344 individuals, with a total of 795 captures (Table 1.5). At all sites, we caught *Peromyscus* spp. (*P. maniculatus* and *P. leucopus*), and *M. musculus*. The majority of species captured in 2019 were *Peromyscus* spp., with only one vole (*M. ochrogaster*) captured (Figure 1.3). The most active field site was Cave field with 150 individuals and 409 total captures, and the least active field site was Hardwick field with 35 individuals and 51 total captures. The top model for survival was the null model indicating that survival rates for all species across the sites was 0.46 (95% CI 0.36-0.57). Probability of capture varied by species and site. *Peromyscus* spp. had the highest probability of being captured but capture trends were consistent across sites. (Figure 1.4).

In the 2020 field season, I captured 5 different species at the 4 field sites; *P. maniculatus*, *P. leucopus*, *M. musculus*, and *M. ochrogaster* were located at all field sites while *B. brevicauda* was only at two sites. A total of 653 individuals were captured with 2163 total capture events (Table 1.9). The most frequently caught species was *P.*

maniculatus with 1,655 total captures (1.5). Compared to the 2019 field season, I capture a more diverse number of species represented by the addition of *M. ochrogaster* and *M. musculus*. *B. brevicauda* was the least frequently caught species, being caught a total of 6 times with no recaptures. The most active field site was Blanding field with 647 total captures and 174 individuals, and the least active field site was Pat field with 447 total captures and 129 individuals.

The Poisson generalized linear model indicated significant differences between treatment, primary periods, and the interaction of the two on small mammals TNI ($p < .001$; Figure 1.6). The EMMs post-hoc test revealed pairwise differences in the interaction of the treatments specifically with the T0 treatment. The number of small mammals increased during the T0 treatment with a P-value of $p < .001$. The post-hoc test also revealed a significant trend of TNI growth stopping or reducing growth rates for small mammals after the T4 treatment suggesting that individuals in the T4 treatment emigrated out of the area. The T0 treatment has the opposite effect of the T4 treatment. In areas where T4 has a decrease in small mammals, T0 maintained the continuous growth of small mammals in the area. The TNI was increasing continuously throughout each primary period but depending on the treatment the number of small mammals only increased slightly. This increase was the lowest for the T4 treatment and highest for the T0 treatment, while the T2 treatment remained in the middle of the two.

The Poisson generalized linear model for voles revealed differences in both treatment and all the primary periods except period 1 ($p < .001$; Figure 1.7). The EMMs post-hoc test revealed significant pairwise differences in the interactions of T4 with T0 and T2 with $p < .01$, indicating a response to the treatment (Figure 1.7). The number of voles decreases when the first treatment is applied. This was especially true for treatment T4 which consistently had a lower number of voles compared to the other treatments. Treatment T0 maintained the trend seen in small mammals with only voles whereas the number of individuals is consistently increasing.

Results for the Pollocks Robust Design Model for 2020 data showed that for all species survival varied by sex, time, grid, and site. Females (S 51% - 88%) appear to have a slightly higher survival rate compared to males (S 45% - 85%); however, there is a

substantial amount of overlap between survival for both sexes (Figure 1.8). In the 2020 models, grid represents the different treatment periods (i.e., a different termination period of the cover crop). The apparent survival follows a parabolic shaped curve over time, which is consistent trend across all four field sites, treatments, and species. For all sites, survival starts at a high point dropping during the 2nd primary period, only to start increasing again through the last capture period. All grids exhibited this trend with slightly varying estimates of survival. In 2020, capture probability depended on species as well as grid (Figure 1.9). *M. musculus* had the lowest capture probability (SE) and the *P. maniculatus* had the highest capture probability. *M. musculus* failed to be captured at any of the four field sites at grid B (i.e., treatment T4), which appears to be a coincidence, as the same was true for *P. leucopus* and the C Grids (i.e., treatment T2). For all the species, the capture probability follows a consistent pattern of having the highest capture probability on the third day of trapping. This is also true for all secondary periods except for the second primary period.

DISCUSSION

I successfully refined a method for scouting voles in agricultural fields; allowing me to catch 91 voles in addition to the total 2959 captures of small mammals between the two field seasons. These captures allowed me to gain insight into small mammal survival and detection rates during habitat modification, which has not previously been examined in North America. My hypothesis that early cover crop termination as a method for reducing small mammal abundance was supported by the reduction or leveling off of the TNI post treatments as compared to the control population's continued to grow. I also found that population parameters during this drastic habitat change were similar to other populations in more stable systems.

Between my two field seasons in 2019 and 2020, there were consistencies in the species diversities but vast differences in the species abundances. Improvements in determining if a colony was active contributed to the increase in vole captures from one individual in 2019 to 91 individuals in 2020. During 2019, I followed scouting information from Hines (1993) and Witmer et al., (2009), where signs consisted primarily of burrow entrances, runways, and scat. The process of scouting became more selective

and intensive due to the lack of vole captures in the first season. Signs of voles only met the criteria if there were multiple burrows in an area, fresh scat, recent vegetative clippings. However, because scouting took place during the winter, it was challenging to decipher how recent fresh scat and vegetative clippings were. This led to the creation of the "X" method to determine activity. This method was successful in accurately locating voles, and the capture rate of voles increased significantly. These changes led to a substantial number of vole captures, though this was a more time-intensive search.

Another potential explanation for the increase in captures is the increase in trapping effort that took place in 2020. In 2019, there was a total of 2295 trap nights whereas 2020, we had twice the trap nights with 4590. The amount of trapping effort can impact estimates of population dynamics, such as inaccurate population parameter estimations, because of this we transition from trapping once a month to twice a month (Bovendorp et al., 2017, Weldy et al., 2019). Given the increase in effort but uniform capture of voles across all sessions, it appears that the voles were not trap shy, but the locations in 2019 were not supporting a vole population. During 2020 I had twice the number of primary periods than in 2019, allowing for a longer time to catch new individuals. However, when comparing the number of individual *Peromyscus* spp. from 2019 to 2020, they are not greatly different. A similar number of TNI from each field season supports the idea of how the scouting efficacy improved in 2020 to capture voles and the 2019 field season had a sufficient number of primary periods to capture a high number of individuals that are present in the study grid.

The species diversity found in my grids was similar to other studies with comparable agricultural landscapes (*Zea mays*), specifically the Midwest to South regions of the United States. I identified 5 different species, *P. maniculatus*, *P. leucopus*, *M. musculus*, *M. ochrogaster*, and *B. brevicauda*, all of which are considered habitat generalist species (Pinkert et al., 2002, Schwer, 2011). The species diversity remained consistent throughout the field season despite the transitions in vegetation from anthropogenic impacts such as planting or harvesting (Pinkert et al., 2002, Schwer, 2011). Similar to other studies, we did not have multiple re-capture of *B. brevicauda* due to high mortality rates in traps (Shonfield et al., 2013). *M. musculus*, had the lowest

number of individuals and lowest rate of recapture. This may be caused by two potential ecological processes, *M. musculus* is an invasive species that has been thriving on weed seed predation and has a lower rate of capture during winter months, and they use the agricultural fields as a way to disperse (Brown, 1953, Lorenz & Barrett, 1990). However, their first preference of dispersal is using man-made structures such as fences (Lorenz & Barrett, 1990) which were not present close to any of the trapping grids potentially limiting the possibility of encountering the species.

In my study in 2020, all grids and fields presented the same survival trend, a decrease after the first primary period then a slight increase in survival during the final week. The uniformity across treatments suggests that the decrease is due to factors other than cover crop termination. Weather can directly impact survival rates or population levels, but long extended winters at a northern latitude is generally where these impacts are seen. (Korlund & Steen, 2006, Getz et al., 2007, Berl et al., 2017, Giraudoux et al., 2019). In Kentucky, the weather matched a long-extended winter for the 2020 field season; however, no extreme weather events took place during my capture seasons. In small mammals, there can be seasonal weather trends that cause fluctuations in small mammal population density as a result of weather-related mortalities, higher risks of predation, lack of cover and food sources (Cole & Batzli, 1978, Korlund & Steen, 2006). Our survival rate follows the similar parabolic shape of other small mammal populations during the winter months in the Midwest and upper southern regions of the United States (Berl et al., 2017). Mice and voles produce a majority of their offspring and have higher survival rates during spring and summer seasons (Getz & McGuire, 2008). Despite the reflected impact of treatment on TNI size it does not appear to be due to a decrease in survival rate and therefore more likely due to increased emigration.

A decrease in food sources is an indirect impact that weather can have on survival. In the winter, there are fewer high-quality food sources when compared to the rest of the agricultural growing season; less high-quality food resources could lower survival (Cole & Batzli, 1978). Longer periods of cold weather prevent new edible green vegetation from growing, limiting food resources. Survival rates of *M. ochrogaster* could be more dependent on food availability than cover (Getz et al., 2005). I do not believe

this was the case with our study population. Winter rye (*Secale cereal*) is a cool weather crop that will grow in cool climates, such as fall, winter, and spring in Kentucky. In the 2020 field season, I observed multiple *M. ochrogaster* consuming rye cover crops (*Secale cereal*) as a food source. When releasing *M. ochrogaster* back into the field site, it was easy to keep track of the individuals as they made their way through the field. Instead of heading into the burrow, some individuals would stop at cover crops and consume the vegetation on the leaves of the *Secale cereal*. This observation was made when there were other potential vegetative resource options in the agricultural field for the voles to consume. It directly contrasts Prieur and Swihart (2020), who used a combination of wild caught and lab raised *M. ochrogaster* and *M. pennsylvanicus* in a lab feeding trial and found these species did not prefer cover crop when presented with alternatives. The difference between my observation and their results could be due to laboratory settings compared to field settings. In a field setting, food is not always readily available, and foraging instincts and pressure will be demining the vole's actions. In a lab setting, there is less predation pressure, and the environment is controlled from extreme temperature variation, thereby limiting environmental stress on the individuals (Koskela & YlÖnen, 1995). This finding does potentially complicate the hypothesis that a specific type of cover crop could be planted that *Microtus* spp. does not consume.

I found that the Poisson model showed the treatment to be significant with all the small mammals and voles. The number of small mammals decreases when the first treatment is applied. This can be drastically seen with the vole species, who after the treatment T4 consistently have a lower number compared to the other treatments. The loss of habitat and food could cause the small mammals to resort to emigrating out of the area or they risk a higher potential for predation. Multiple studies in Europe on the common vole (*Microtus arvalis*) have shown similar results when removing vegetation by mowing or harvest (Jacob, 2003). For the common vole, the decrease in individuals is believed to be caused by emigration (Bonnet et al., 2013). This would adequately fit what happened with my data, survival rates remained consistent throughout the trapping period but the TNI of small mammals decreased in the T4 treatment. Survival typically decreases immediately after a change to the habitat for a short period of time but then begins to increase. Mowing will also cause the home range size of *M. arvalis* to shrink

(Jacob & Hempel, 2003). Hines (1993) found that removing cover crops one month earlier than planting produced the highest plant yield, for which he hypothesized was a result of forcing the voles to leave the area due to a lack of resources. My study seems to confirm that voles will leave areas with cover crop treatment occurring earlier.

Developing methods to control vole populations or behavior will be key in mitigating vole damage. Early cover crop termination is a practice farmers can implement to reduce vole damage based on my results. Other possible methods to combat the increasing number of vole populations would be to combine scouting efforts with an integrated spot plowing method. The method I devised for scouting was accurate at locating active vole colonies in agricultural fields. Utilizing the ability to identify vole trouble spots and pairing it with spot treatments of plowing could drastically decrease vole population numbers while retaining the conservation of soil in the rest of the field. Plowing fields have already been found as a very effective method in managing vole populations but is not an ideal practice for the environment (Jacob & Hempel, 2003, Witmer et al., 2009). Minimum tillage was developed to protect soil from wind and water erosion and can be beneficial to the physical improvements of soil (Busari et al., 2015). The use of minimum tillage could be an ideal method in situations where populations are increasingly high, however, this method has not been tested in agricultural fields with vole damage issues, and further research needs to investigate to determine the effectiveness of this method (Prieur & Swihart, 2020).

The existing literature on small mammals, specifically voles in agricultural fields, is heavily focused on the changing population cycles that vole species exhibit (Boonstra, 1994, Getz et al., 2001, Krebs, 2013). There are multiple studies on the cycles of vole populations, but most ignore the short time frame of months and focus on years. As valuable as that information is, it does not aid us in understanding how the different sizes vole populations are impacting farmer's agricultural fields. In North America there are not many studies focused on *Microtus* spp. in agricultural settings. Most of the existing literature comes from European agricultural systems (Fischer et al., 2011, Jareño et al., 2014, Rodríguez-Pastor et al., 2016). Future work should focus on collecting more accurate small mammal population parameters in the cover crop systems, especially pre-

and post-row crop transition. Extending the trapping periods that I utilized would allow insight into survival estimates over more of the seasons as well as adding more years of data during the same trapping period and if that data upholds to the population parameter estimates I found.

Most studies for *Peromyscus* in agricultural systems focus on the use of edge habitat for forested habitat next to agricultural fields (Cummings & Vessey, 1994, Berl et al., 2018). Expanding our knowledge of survival and populations in solely cover crop fields would be beneficial to increasing our understanding of rodents in the complete agricultural system. When comparing our data to other studies in row crops, our survival rates and abundance were similar for *P. maniculatus* (Berl et al., 2017). This is unexpected since *P. maniculatus* have adapted to live in the monoculture agricultural ecosystems; their mandibles have even adapted to the amount of waste grains they now consume as part of their regular diet (Doudna, 2014, Berl et al., 2017). In comparison to other studies, it was unexpected that *P. maniculatus* survival was the same as *M. ochrogaster*. I was expecting *P. maniculatus* to have a higher rate of survival due to their adaptability.

One major piece of critical information that is still missing on voles in soybean fields is the quantifiable amount of damage that voles are causing in soybean crops. There is little to no information on how much damage is being done, just the off-the-cuff estimates from producers when reporting the damage. Voles are causing damage to soybeans, this is known, but it has not been estimated how much of the crop is lost or the subsequent revenue. If the loss of revenue from damage is minimal, then the amount of effort or money spent to mitigate damage would need to be balanced with the overall losses. For other pest species, such as deer, this information is readily available. Countless studies are published on quantifying amounts of damage done by deer due to their browsing, and despite farmer's estimates, several studies have documented little to no impacts on overall field yields except in certain circumstance (Kuželka & Surový, 2018, Rogerson et al. 2010). However, damage can still occur in extremely high densities or fields with extreme browsing pressure (Hinton et al., 2017, Matthews, 2019) highlighting the need to better understand when to expect damage from the species. This

could be a similar situation we face with voles in soybean fields, but we will not know until it is properly researched.

A caveat that needs to be mentioned that could have impacted survival, abundance, and capture probability in 2020, was the premature planting of soybeans in the field. Soybeans were planted after the first termination period in April. This is not following the typical planting season for soybeans as they are generally planted around the beginning of May (Lee et al., 2007). The early planting resulted in soybean plants replacing the vegetative cover at an earlier time period than expected or wanted. This factor could be the reason we did not see similar results in decreasing populations that Hines (1993) saw when removing cover crops earlier from the field. This was not the ideal plan for the field season, despite plantings going slightly askew, the data and information we collected still provides insight into the understudied system.

While I acknowledge that the use of actively used farm fields caused a few slight problems in the project's scientific method, the information gained from using these fields is immensely valuable and aids our understanding of how to manage vole populations in cover crop fields transitioning to soybeans. Future efforts should focus on the addition of VHF radio collars to each species found in the field. Fine-scale detail on the use of cover crops during the transition to row crops has not been researched yet. This would provide more precise information about survival, space use, dispersal, and niche partitioning for the species present in the fields. We do not know much about the movement and dispersal of voles in this habitat, but it is important to understand rodent response to loss of cover crops and if it leads to them leaving the fields. Overall, a multifaceted approach is needed to expand our knowledge of this system, which will lead to a better grasp of effective mitigation methods.

CONCLUSION

There is still a lot unknown about vole populations in agricultural fields. With this study, I was able to improve methods on locating voles in agricultural fields. This allowed for the analysis of small mammal populations. Small mammal population survival rates change throughout the transition from cover crops to soybeans. As expected, they increase throughout spring, the common time frame for breeding. My

hypothesis that the termination timing of cover crops will decrease the survival rate and overall population of small mammals in the fields was found to be significant with a Poisson linear model. It did decrease the overall number of individuals in the field and briefly lowered survival rates, signifying that more research is needed to expand the knowledge on this method. Habitat modification of cover crops paired with another slightly successful mitigation method could be the solution to managing vole populations.

TABLES

Table 1.1 The dates for each cover crop termination period (herbicide removal of cover crops) and soybean planting period for each field site. Fields Jagger, Bland, and Long Grove were all owned by the same producer while Patrick field was by a separate producer. Field sites located in Hardin County, Kentucky, March 2020-June 2020

Field Site	Grid B 1st Termination	Grid C 2nd Termination	Grid A 3rd Termination	Planting Soybeans
Jagger	4/16/2020	4/27/2020	5/14/2020	4/22/2020
Bland	4/16/2020	4/27/2020	5/14/2020	4/22/2020
Long Grove	4/16/2020	4/27/2020	5/14/2020	4/22/2020
Patrick	4/7/2020	4/24/2020	5/14/2020	4/23/2020

Table 1.2 Primary and secondary trapping dates at field sites from agricultural fields in Hardin County, Kentucky, March 2019-June 2019

Field Site	Primary Period	Secondary Period 1	Secondary Period 2	Secondary Period 3
Cave	1	4/26/2019	4/27/2019	4/28/2019
	2	5/25/2019	5/26/2019	5/27/2019
	3	6/25/2019	6/26/2019	6/27/2019
Hardwick	1	4/4/2019	4/5/2019	4/6/2019
	2	5/16/2019	5/17/2019	5/18/2019
	3	6/16/2019	6/17/2019	6/18/2019
Lucus	1	4/12/2019	4/13/2019	4/14/2019
	2	5/19/2019	5/20/2019	5/21/2109
	3	6/19/2019	6/20/2019	6/21/2019
Tab	1	4/19/2019	4/20/2019	4/21/2019
	2	5/22/2019	5/23/2019	5/24/2019
	3	6/22/2019	6/23/2019	6/24/2019

Table 1.3 Primary and secondary small mammal trapping dates at agricultural fields in Hardin County, Kentucky, March 2020-June 2020

Field Site	Primary Period	Secondary Period 1	Secondary Period 2	Secondary Period 3
Patrick	1	4/1/2020	4/2/2020	4/3/2020
	2	4/9/2020	4/10/2020	4/11/2020
	3	4/28/2020	4/29/2020	4/30/2020
	4	5/15/2020	5/16/2020	5/17/2020
	5	6/1/2020	6/2/2020	6/3/2020
	6	6/17/2020	6/18/2020	6/19/2020
Jagger	1	3/21/2020	3/22/2020	3/23/2020
	2	4/6/2020	4/7/2020	4/8/2020
	3	4/23/2020	4/24/2020	4/25/2020
	4	5/10/2020	5/11/2020	5/12/2020
	5	5/27/2020	5/28/2020	5/29/2020
	6	6/12/2020	6/13/2020	6/14/2020
Bland	1	3/24/2020	3/25/2020	3/26/2020
	2	4/14/2020	4/15/2020	4/16/2020
	3	5/1/2020	5/2/2020	5/3/2020
	4	5/18/2020	5/19/2020	5/20/2020
	5	6/4/2020	6/5/2020	6/6/2020
	6	6/20/2020	6/21/2020	6/22/2020
Longgrove	1	3/29/2020	3/30/2020	3/31/2020
	2	4/17/2020	4/18/2020	4/19/2020
	3	5/6/2020	5/7/2020	5/8/2020
	4	5/24/2020	5/25/2020	5/26/2020
	5	6/9/2020	6/10/2020	6/11/2020
	6	6/24/2020	6/25/2020	6/26/2020

Table 1.4 Covariate description and the Robust Design Model modeling sets in which they were included (2019 or 2020 field seasons) for small mammal capture data analysis for Hardin County, Kentucky

Covariates	Definition	Years Used
Sex	Male or female individuals	2019 and 2020
Species	Different taxonomic groups	2019 and 2020
Site	Different field site (Location)	2019 and 2020
SiteGrid (SG)	A combination of site and grid. Added due to no treatment in 2019 but allowed the ability to look at individual grids.	2019
Grid	The treatment (T0, T2, T4) that was applied to each grid	2020

Table 1.5 Robust Design Model List used for apparent survival and capture probability estimates in 2019. Parameters were fitted to be constant while the covariates differ. The parameter not being tested were set to their global model with covariates. Probabilities of capture (p) and recapture (c) modeled as (p=c (.)) and survival remained constant(S(.))

Model	Covariates				
	Time	Sex	Species	Site	SiteGrid (SG)
1					
2	x				
3		x			
4					x
5			x		
6	x				x
7	x		x		
8	x	x			
9			x		x
10		x			x
11		x	x		
12	x		x		x
13	x	x			x
14		x	x		x
15	x	x	x		x
16				x	
17	x			x	
18		x		x	
19				x	x
20			x	x	
21	x			x	x
22	x		x	x	
23	x	x		x	
24			x	x	x
25		x		x	x
26		x	x	x	
27	x		x	x	x
28	x	x		x	x
29		x	x	x	x
30	x	x	x	x	x

Table 1.6 List of top competing models used for parameter estimates of 2019 small mammal capture data from Hardin County, Kentucky. Probabilities of capture (p) and recapture (c) modeled as (p=c (.)) and survival remained constant(S(.))

Model	Parameters					
	Survival	Capture Probability			Temporary Emigration	
		Time	Species	Site	$\gamma(\cdot)=0$	$\gamma''=\gamma'$
1	~	x	x	x	x	
2	~	x		x	x	
3	~	x	x		x	
4	~	x	x	x		x
5	~	x		x		x
6	~	x	x			x

* notation "~" dictates null model

Table 1.7 Robust design models estimating apparent survival (S), temporary emigration (Y^{''}), capture probability(p), and population size (f0) of *Peromyscus* spp. and house mice (*Mus musculus*) sampled from soybean fields in Hardin County, Kentucky, March 2019-June 2019. Competing models are ranked by Akaike’s Information Criterion (AICc). K is the number of model parameters, Δ AIC is the difference between the model and the best model, Weight indicates proportional AIC model weight.

Model	K	AICc	Δ AIC	Weight	Deviance
S(~1)Gamma"(~1)Gamma'()p(~1 + t+ species + site)c()f0(~session)	20	1027.4	0	0.804	529.41
S(~1)Gamma"(~1)Gamma'(~1)p(~1 + t + species + site)c()f0(~session)	19	1030.4	2.980	0.181	534.50
S(~time + SG + species + sex + site)Gamma"(~time)Gamma'()p(~1 + t + SG + species + sex + site)c()f0(~session) (Global)	51	1058.8	31.355	0.001	492.63

Table 1.8 Robust design models estimating apparent survival (S), temporary emigration (γ''), capture probability(p), and population size (f0) of prairie voles (*Microtus ochrogaster*), white footed mice (*Peromyscus leucopus*), deer mice (*Peromyscus maniculatus*), and house mice (*Mus musculus*) sampled from soybean fields in Hardin County, Kentucky, March 2020-June 2020. Competing models are ranked by Akaike's Information Criterion (AICc). K is the number of model parameters, Δ AIC is the difference between the best model, Weight indicates proportional AIC model weight.

Model	K	AICc	Δ AIC	Weight	Deviance
S(~time + grid + sex + site) γ'' (~1)p(~1 + s:t + grid + species)c()f0(~session)	42	3234.505	0	1.47E-01	2451.076
S(~time + grid + sex + site) γ'' (~1)p(~1 + s:t + species)c()f0(~session)	40	3234.638	0.133	1.38E-01	2455.368
S(~time * grid + site) γ'' (~1)p(~1 + s:t+ species)c()f0(~session)	47	3237.172	2.667	3.88E-02	2443.311
S(~time + grid + site) γ'' (~1)p(~1 + s:t+ grid + species)c()f0(~session)	41	3237.702	3.196	2.98E-02	2456.353
S(~time + grid + site) γ'' (~1)p(~1 +s:t + species)c()f0(~session)	39	3237.827	3.221	2.79E-02	2444.377
S(~time * grid + sex) γ'' (~1)p(~1 + s:t + grid + species)c()f0(~session)	47	3238.238	3.733	2.28E-02	2444.377
S(~time + sex + site) γ'' (~1)p(~1 + s:t + species)c()f0(~session)	38	3238.43	3.924	2.07E-02	2463.311
S(~time + sex + site) γ'' (~1)p(~1 + s:t + grid + species)c()f0(~session)	40	3238.53	4.024	1.97E-02	2459.259

Table 1.9 The total number of small mammal captures by species and field site from agricultural fields in Hardin County, Kentucky, March 2019-June 2019

Field Site	Species	# of Individuals	Total Captures
Cave	<i>Peromyscus spp.</i>	142	400
	<i>Mus musculus</i>	8	9
	<i>Microtus spp.</i>	0	0
Lucus	<i>Peromyscus spp.</i>	74	171
	<i>Mus musculus</i>	10	12
	<i>Microtus spp.</i>	0	0
Tabb	<i>Peromyscus spp.</i>	69	145
	<i>Mus musculus</i>	5	6
	<i>Microtus</i>	1	1
	<i>ochrogaster</i>		
Hardwick	<i>Peromyscus spp.</i>	30	45
	<i>Mus musculus</i>	5	6
	<i>Microtus spp.</i>	0	0
Total		344	795

Table 1.10 The total number of small mammal captures by species and field site from agricultural fields in Hardin County, Kentucky, March 2020-June 2020

Field Site	Species	# of Individuals	Total captures
Blanding	<i>Peromyscus maniculatus</i>	142	582
	<i>Peromyscus leucopus</i>	4	11
	<i>Microtus ochrogaster</i>	18	42
	<i>Mus musculus</i>	9	11
	<i>Blarina brevicauda</i>	1	1
Jagger	<i>Peromyscus maniculatus</i>	90	321
	<i>Peromyscus leucopus</i>	49	132
	<i>Microtus ochrogaster</i>	39	104
	<i>Mus musculus</i>	13	19
	<i>Blarina brevicauda</i>	3	3
Longgrove	<i>Peromyscus maniculatus</i>	94	369
	<i>Peromyscus leucopus</i>	4	8
	<i>Microtus ochrogaster</i>	26	55
	<i>Mus musculus</i>	30	57
	<i>Blarina brevicauda</i>	2	2
Pat	<i>Peromyscus maniculatus</i>	94	383
	<i>Peromyscus leucopus</i>	10	23
	<i>Microtus ochrogaster</i>	8	15
	<i>Mus musculus</i>	17	26
	<i>Blarina brevicauda</i>	0	0
Total		653	2164

FIGURES

Figure 1.1 Photos taken from the different field sites over the course of the field season in 2020. Photo A represents a vole colony that is in dead corn and vegetative matter. Photo B highlights both the presence of plant material being dragged inside of a burrow along with a vole runway moving from the entrance of the burrow to bottom middle of the image. Photo C is an example of a colony located under dead vegetation which is providing cover to the colony and the runways.

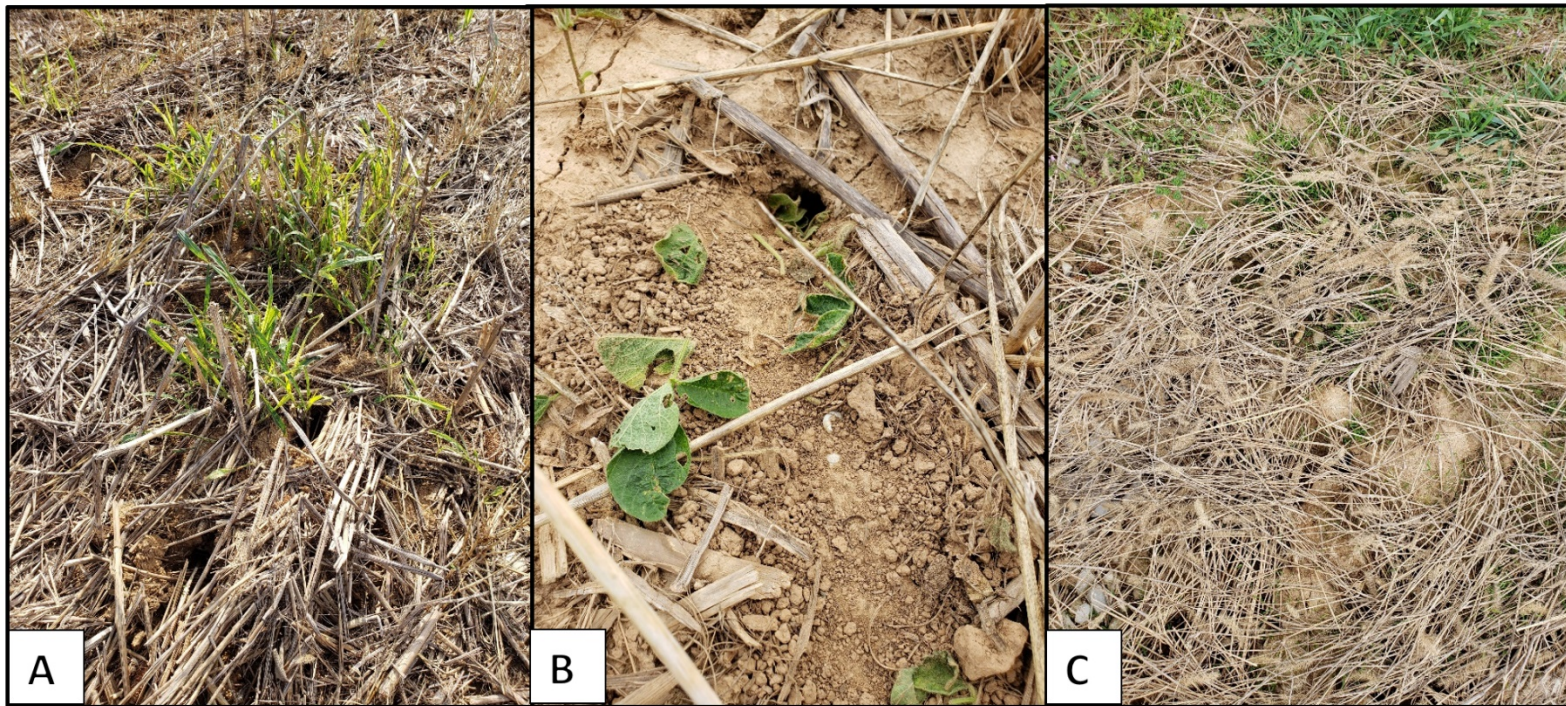


Figure 1.2 Representation of trapping grid used for all small mammal trapping locations in Hardin County Kentucky during 2019 and 2020 study. The outer traps are 10m apart while the center trap is 7 meters inward. The best way to describe this pattern is the repeating image of the 5-side of a die.

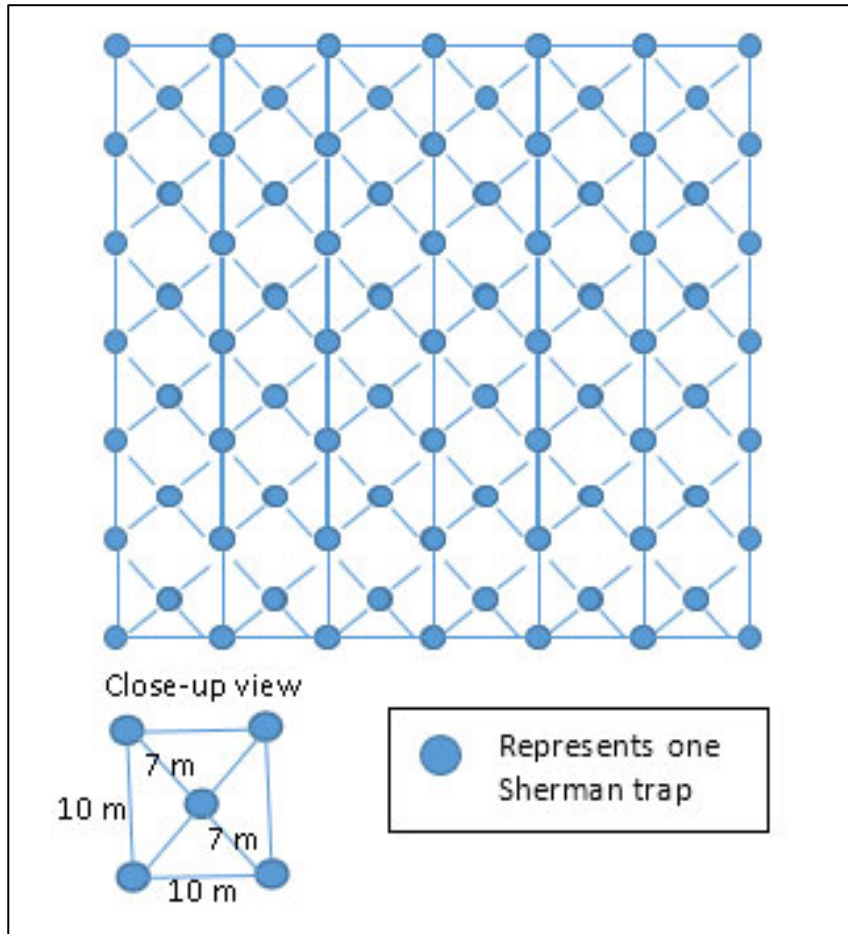


Figure 1.3 Total combined number of individuals for 4 different species, prairie voles (*Microtus ochrogaster*), white footed mice (*Peromyscus leucopus*), deer mice (*Peromyscus maniculatus*), and house mice (*Mus musculus*) sampled from agricultural fields in Hardin County, Kentucky, March 2019-June 2019. Field identifiers appear across the top.

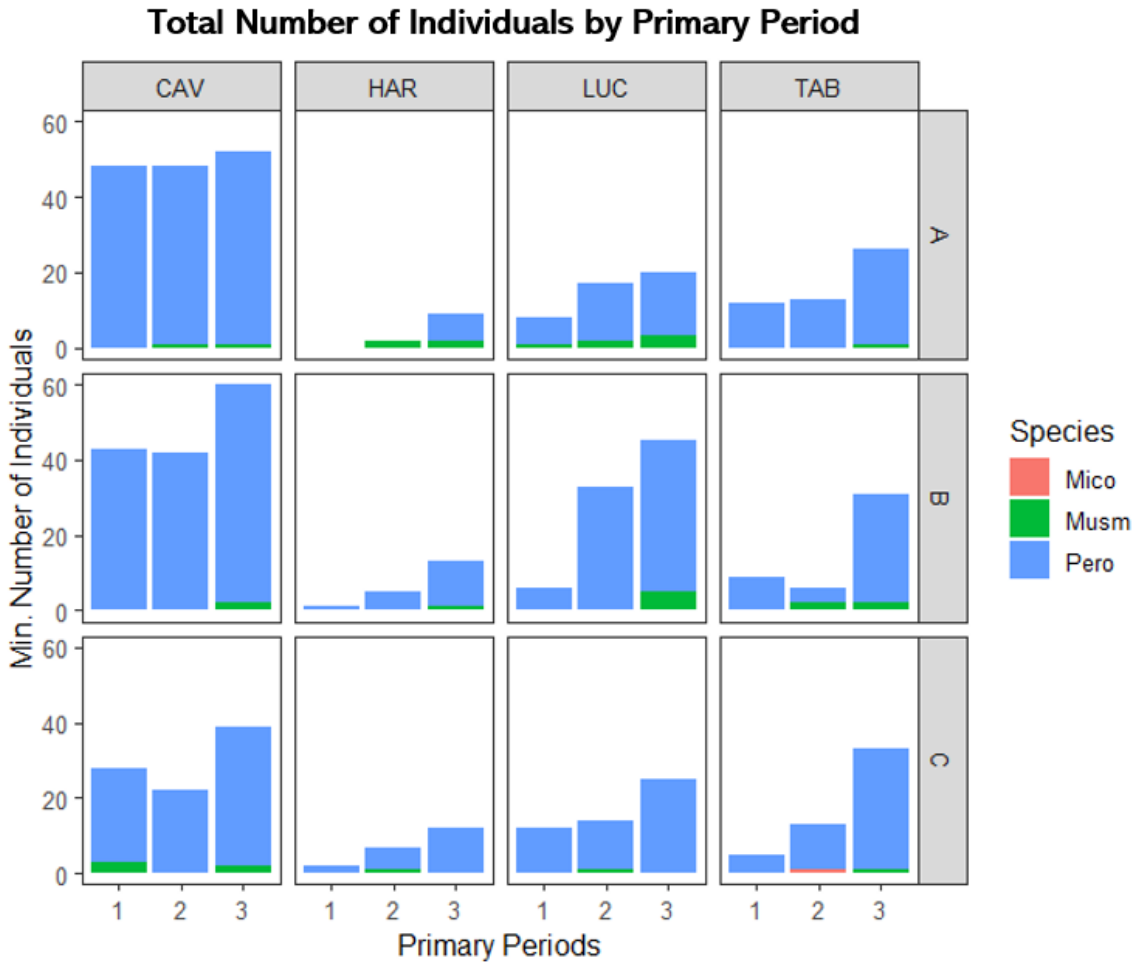


Figure 1.4 Capture probability for 4 different species, prairie voles (*Microtus ochrogaster*), white footed mice (*Peromyscus leucopus*), deer mice (*Peromyscus maniculatus*), and house mice (*Mus musculus*) sampled from agricultural fields in Hardin County, Kentucky, March 2019-June 2019. Field identifiers appear across the top.

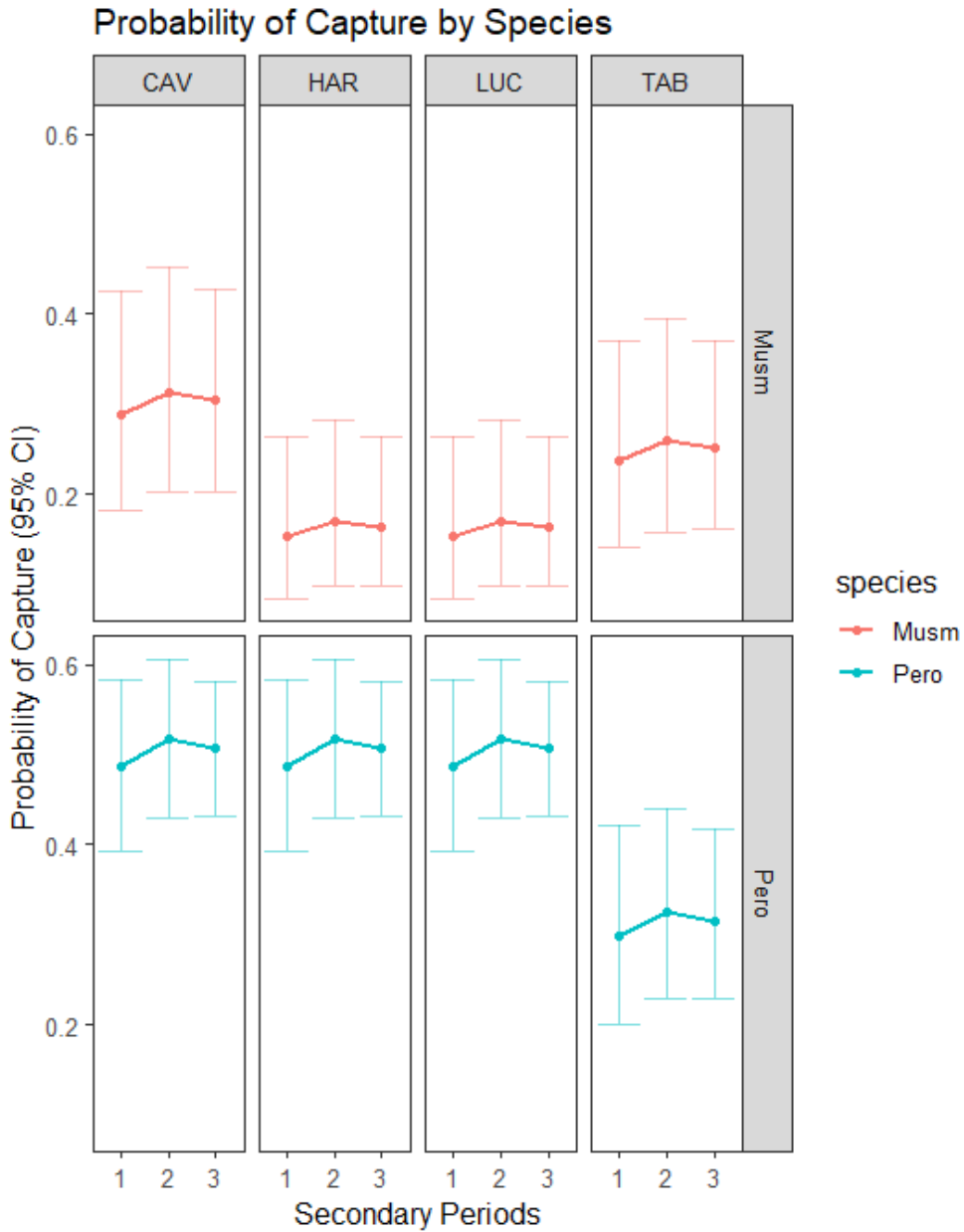


Figure 1.5 Total combined number of individuals for 4 different species, prairie voles (*Microtus ochrogaster*), white footed mice (*Peromyscus leucopus*), deer mice (*Peromyscus maniculatus*), and house mice (*Mus musculus*) sampled from agricultural fields in Hardin County, Kentucky, March 2020-June 2020. Field identifiers appear across the top.

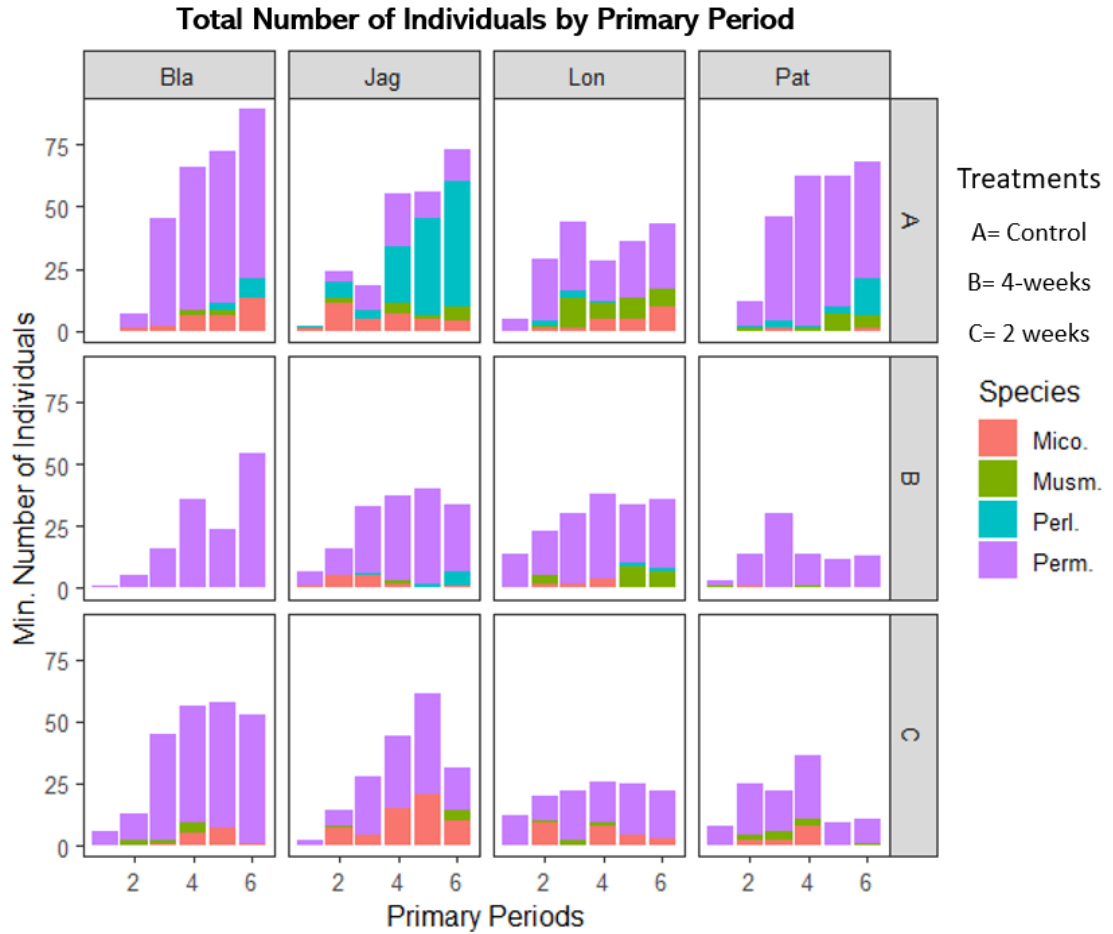


Figure 1.6 Results of the generalized linear poisson model for examining the impacts of cover crop treatment timing on small mammals TNI. Sampled from agricultural fields in Hardin County, Kentucky, March 2020-June 2020. Field identifiers appear across the top.

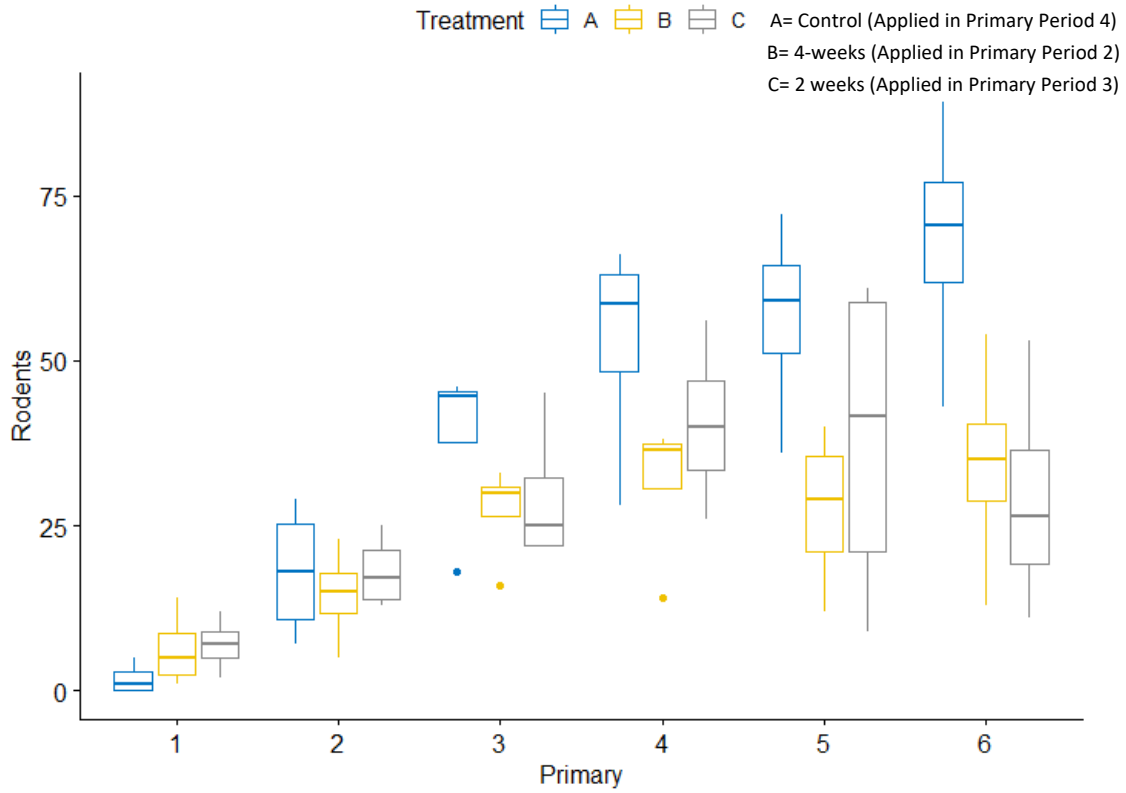


Figure 1.7 Results of the generalized linear poisson model for examining the impacts of cover crop treatment timing on small mammals TNI. Sampled from agricultural fields in Hardin County, Kentucky, March 2020-June 2020. Field identifiers appear across the top.

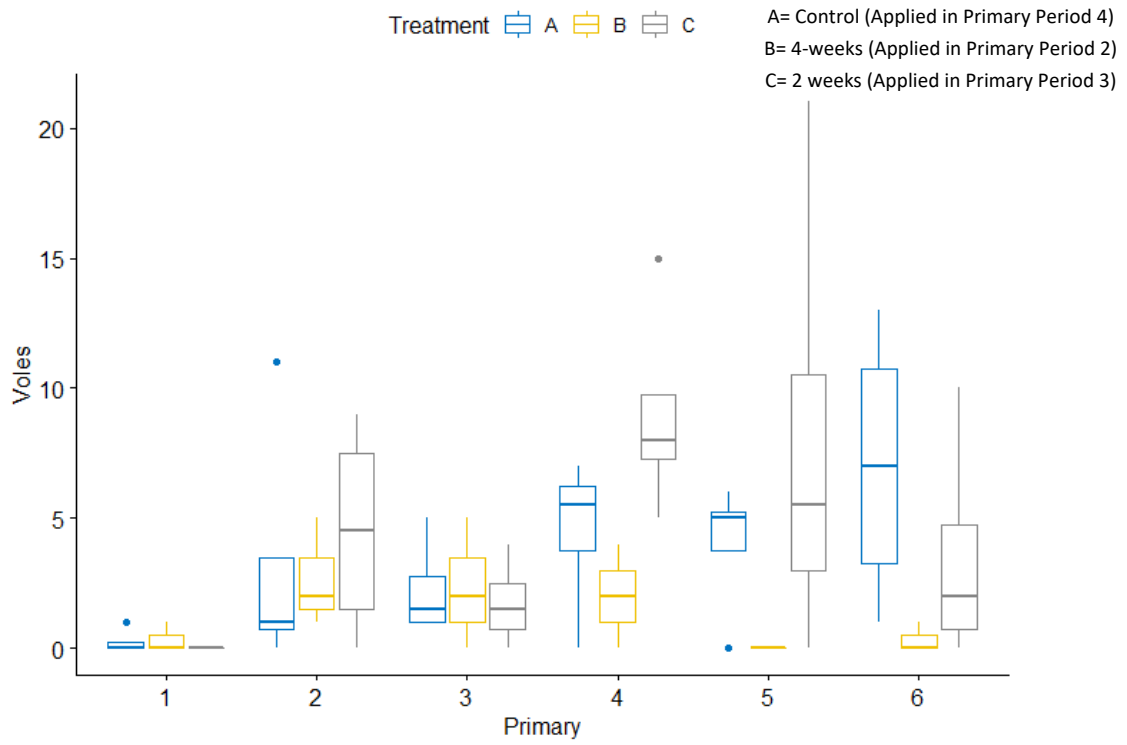


Figure 1.8 Survival estimates for prairie voles (*Microtus ochrogaster*), white footed mice (*Peromyscus leucopus*), deer mice (*Peromyscus maniculatus*), and house mice (*Mus musculus*) sampled from agricultural fields in Hardin County, Kentucky, March 2020-June 2020. The Black dashed line represents when the treatment was applied.

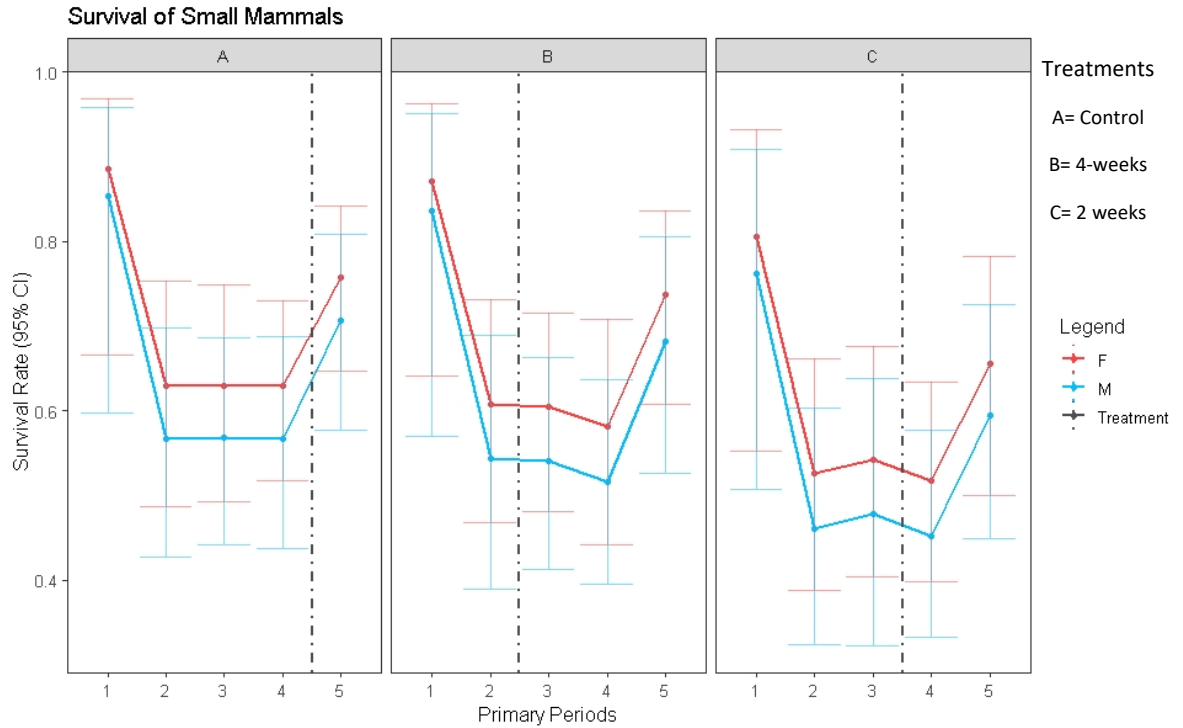
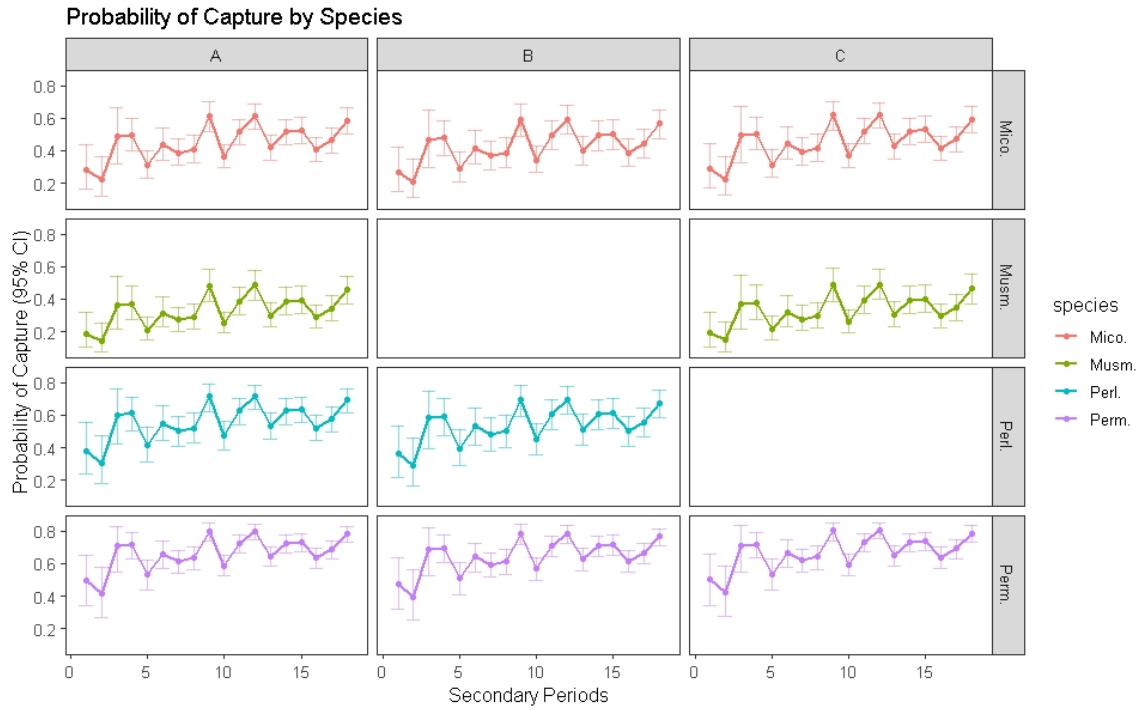


Figure 1.9 Capture probability of 4 different species, prairie voles (*Microtus ochrogaster*), white footed mice (*Peromyscus leucopus*), deer mice (*Peromyscus maniculatus*), and house mice (*Mus musculus*) sampled from agricultural fields in Hardin County, Kentucky, March 2020-June 2020.



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