

Effects of Ecological Edges on Mammal Diversity in Western Pennsylvania Forests

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Habitat fragmentation is one of the most significant threats to biodiversity and ecosystem function worldwide. The edge effect refers to the numerous effects of proximity to edges on ecosystem elements and is one important consequence of habitat fragmentation. To measure the impact of edge on terrestrial mammal diversity I set camera traps along transects in northern hardwood forest fragments in three properties managed by the French Creek Valley Conservancy in Crawford County, Pennsylvania. Four camera traps were placed 200 meters apart at each site, Raup's Wildlife Sanctuary, Mammoth Run, and Greendale Cemetery. At all sites, two cameras were placed in close proximity (approximately 20 meters) to manmade ecological edges, and the other two were placed in the interior forest fragments. Cameras were active 24 hours a day with a 30 second delay for two weeks consecutively at each site, with all trapping taking place between September and November 2023. Overall mammal richness and species presence along the transects were measured, along with diversity using the Shannon-Weiner Diversity index. All measures compared edge areas to core areas. At all sites, there were more species detected ($n = 4$ compared to $n = 2$), more total detections ($n = 115$ compared to $n = 64$), and more relative richness at core areas than at edge areas. Core areas at all sites had greater diversity (H_s) and evenness (J'). However, none of these trends were found to be statistically significant. Small sample size, site heterogeneity, short time scale, and disproportionately high percentage of white-tailed deer (*Odocoileus virginianus*) detections were potential contributors to the lack of statistically significant trends. This research extended camera trap fragmentation research into a new, previously unstudied area, provided information about the value of a specific study method for different groups of mammals, and provided information about ecosystem dynamics in a land conservancy that can be used to inform conservation efforts.

Keywords: habitat fragmentation, biodiversity, mammals, edge effect, French Creek, Pennsylvania, Northern hardwood forest.

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Introduction

Land use, and its accompanying habitat destruction and fragmentation, are some of the most significant causes of global biodiversity loss today (United Nations Environment Programme). Forest loss is one important dimension of the issue. According to the United Nations Environment Programme, “Since 1990, around 420 million hectares of forest have been lost” worldwide. As natural ecosystems are altered through development, they often become fragmented into smaller, discontinuous areas. This alters the composition and function of ecosystems, which can further contribute to biodiversity loss in a nonlinear way, with continued loss of diversity even within intact habitat inside fragments (Haddad et. al, 2015).

A 2015 synthesis of current research on habitat fragmentation covering three decades and five continents found that habitat fragmentation threatens forests by disrupting the natural cycling of nutrients, changing biomass distribution, and altering species richness and composition (Haddad et. al, 2015). This makes studying the effects of fragmentation and proximity to edges necessary to understand ecological trends from local to global scales. Some of the specific details of how habitat fragmentation affects different components of different ecosystems remains to be studied. A 2001 synthesis of 20 habitat fragmentation studies found inconsistency regarding the effects on species diversity and richness at different fragment sizes (Debinski & Holt, 2001). Effects also differed with organism type and level of classification.

Fragmentation can favor animals that tolerate disturbed ecosystems, including White-tailed deer (*Odocoileus virginianus*), leading to population imbalances. Another tangible consequence of habitat fragmentation is an increase in white-tailed deer populations and deer related environmental problems (Knight et. al, 2009). Deer overpopulation is associated with damage to crops, damaging forests, traffic injuries and deaths, the increased spread of Lyme disease, and increased spread of invasive species (Knight et. al, 2009; Witmer & DeCalesta, 1991). To deal with the problems presented by habitat fragmentation, research needs to understand the mechanisms by which it alters ecosystems.

The edge effect is one such mechanism, and one of the most significant. It can alter the abiotic and biotic components of an ecosystem by affecting wind and temperature, has been shown to alter leaf litter insect populations up to 300 meters away from the edge, and make ecosystems more susceptible to invasive species (Debinski & Holt, 2001), for example. Ecological edges can also impact seed dispersal, seedling survival rates, and overall biodiversity, including mammal diversity (Asquith & Mejia-Chang, 2005). What constitutes an ecological edge is context dependent, but at the broadest level, an edge is an area where one type of habitat ends (Ries L. & Sisk, T. D, 2004). Edge effects are common among mammals and birds, but vary widely with individual species. The term edge can describe a zone in which one natural ecosystem transitions to another (Ries L. & Sisk, T. D, 2004), typically called an ecotone

(Tõnisalu & Väli, 2022), a zone in which a natural ecosystem transitions to an agricultural area, which often impacts rodent diversity (Tõnisalu & Väli, 2022), or a zone in which an ecosystem intersects another form of human development. Different types of edges can impact populations of certain animals, especially rodents, to the extent that even edges composed of fields planted with different agricultural crops can have measurable impacts (Tõnisalu & Väli, 2022).

Mammal richness has been used as an indicator of ecosystem quality as it pertains to conservation (Green et. al, 2020). Trail cameras are an efficient way of measuring mammal richness. Small mammals especially are efficient indicators of overall ecosystem function (Pearce, 2005), though surveys of mammal species of all sizes from deer (Green et. al, 2020), to mice and voles (Pearce, 2005) can give insights into the function of certain aspects of an ecosystem, such as browsing or predator dynamics (Tõnisalu & Väli, 2022.) It has even been shown that the edge effect can alter mammal behavior, including deer browsing habits (Pierce et. al, 2015) and can dramatically alter rodent diversity (Tõnisalu & Väli, 2022). Mammals are an important community to survey because they are involved in a high number of ecological functions, and their species diversity can be easily and accurately estimated using camera trapping (Rovero, 2014). Mammals occupy niches ranging from small seed dispersers to large browsing herbivores to apex predators (Tõnisalu & Väli, 2022; Weaver, 2000). Furthermore, a 2010 study comparing camera traps to physical traps found that the two were similarly effective for sampling small mammals when presence is the desired variable (Bondi et. al, 2010).

Pennsylvania is home to large amounts of forest land, the predominant forest type in the northwestern portion of the state being northern hardwood forest (Pennsylvania Department of Conservation of Natural Resources, n.d.). Agriculture makes up a significant portion of human land use in Pennsylvania and provides 83.8 billion dollars to the state each year (The Nature Conservancy, no date), so agricultural land use and biodiversity represent potentially competing interests that are both necessary. As such, understanding the dynamics by which land use affects the biodiversity of northern hardwood forests could be an important step that can inform decisions regarding natural resource management in future efforts to balance the two necessities.

Pennsylvania has experienced dramatic changes in forest cover over the last century, and is currently experiencing regrowth, but little research has been done in the region about the effects of fragmentation and edges on mammal presence. This study will investigate how proximity to edges affects mammal richness in a western Pennsylvania northern hardwood forest, and contribute to the body of research about fragmentation, edge effect, and mammal richness by studying a new area.

Northwest Pennsylvania contains the watersheds of French Creek and the Allegheny River (National Wild and Scenic River System, n.d.), which are part of the Ohio river watershed, and ultimately feed into the Mississippi River and the Gulf of Mexico. Ecosystems in Pennsylvania can affect water

quality in Lake Erie, French Creek, and the Allegheny River. The French Creek Valley Conservancy (FCVC) is a nonprofit organization that preserves more than 3000 acres of wild land in the French Creek watershed. French Creek alone is known as “one of the most biologically important waterways in the entire country” (French Creek Valley Conservancy, n.d.). The FCVC’s purpose is to protect biodiversity within the watershed, which is home to 27 native freshwater mussel species and eighty fish. With limited resources to allocate to conservation efforts, it is important for studies in the FCVC to efficiently estimate ecosystem dynamics. The effect of ecological edges on mammal diversity represents an efficient entry point into the problem. Research took place in the FCVC, and will serve not only to expand fragmentation research to a new area, but also to help conservation authorities understand one important aspect of the forest ecosystems on conservancy land. This study measured the presence of small, medium, and large mammals along transects moving away from a forest edge using camera traps in three French Creek Valley Conservancy Properties.

It was predicted that small mammals would show the greatest variation in presence in relation to edge proximity and it was predicted that no variation would be observed in large mammals due to home range size (Howell, 1954). It was predicted that among small mammals, species with tolerance to a wider range of ecological conditions would be less affected by proximity to edges than those with a narrower range of habitat requirements. It was predicted that the Shannon Wiener diversity index would be higher at interior points than on points in close proximity to edges. A higher number of species was predicted to be detected at core points than at edge points on the transects, and a higher number of overall detections was predicted at core points. It was predicted that among small mammals, effects of different types of edges would vary by species.

Methods

Study sites

French Creek Valley Conservancy properties Raup's Wildlife Sanctuary, Mammoth Run, and Greendale Cemetery were surveyed.

Raup's Wildlife Sanctuary is a rectangular, 31-acre plot of forested land (French Creek Valley Conservancy, 2024) east of Meadville, Pennsylvania. It is in the middle of a rural landscape containing a mix of forest and agricultural land. The property is bordered on one side by a gravel road adjacent to some housing and fields. On two sides, it is bordered by large stretches of private forest, and on the last it borders a small stretch of trees that give way to agricultural fields and yards. The entire plot is made up of forest, and also contains multiple seeps and vernal pools.



Raup's Wildlife Sanctuary (French Creek Valley Conservancy, 2024).

Mammoth Run is an 86 acre, irregularly shaped property in a moderately developed landscape in Conneaut Lake, Pennsylvania (French Creek Valley Conservancy, 2024). Surveying took place in a rectangular area in the northeast corner of the property, similar in size to Raup's Wildlife Sanctuary. The surveyed area borders a paved road, a housing development, an uncultivated field, and finally a boundary

that is on one end uninterrupted woodland, and on the other a single house and yard. The surveyed area contains forest with varying degrees of undergrowth, a wet area overgrown with water grasses, and small trees in the shape of a narrow strip that runs through the area's center, and an abandoned apple orchard. Near the paved road, there is heavy brush that quickly gives way to open forest with no understory, then grows again with proximity to the wet area in the center. The area bordering the field, opposite the road, also contains a thick understory of shrubs and canes. The border with the housing development contains the abandoned apple orchard, which is moderately grown over with shrubs and canes. The boundary made up of woodland and the single house is clear of understory until near its intersection with the road and the field on opposite sides.



Mammoth Run (French Creek Valley Conservancy, 2024).

Greendale Cemetery is a narrow, rectangular, 75-acre property in the middle of a developed area of Meadville, Pennsylvania (French Creek Valley Conservancy, 2024), spanning a deep, steep sided ravine formed by a creek. The whole property is wooded and contains extremely old stands of trees including eastern hemlocks. The area surveyed was a roughly square section of forest surrounding the ravine at the northern boundary of the property. It was bounded by a large cemetery with a small paved road, a stretch of private forest opposite that, a short stretch of private forest in close proximity to a paved

road spanning the two boundaries to the north, and a large continued section of the forested ravine within the conservancy property to the south.



Greendale Cemetery (French Creek Valley Conservancy, 2024).

Study design

Data on overall mammal species richness and mammal diversity along transects (Pearson & Ruggiero, 2003) and presence of individual mammal species by location on the transects was recorded. Two transects were used at each site, with two cameras per transect. Transects used 200 meter spacing between each camera, and 200 meter spacing between individual transects. Transects started as close as possible (within 20 meters) to prominent, man-made ecological edges, and extended inwards towards core forest. This scheme was followed at all sites for consistency, based on the maximum cameras allowed at the smallest site, Raup's Wildlife Sanctuary, using the 200 meter spacing scheme recommended by Smith et al in their 2022 study. Cameras were active at each site for two weeks, to meet the minimum

recommendation of a 2020 study by Kays et. al. Transects were measured physically using a measuring tape and a compass, and camera coordinates and distance were recorded and checked with ArcGIS Field Maps. When the locations of the four cameras were selected using the measuring tape, the nearest tree to the 200-meter spaced points was chosen to mount the cameras.

Mammal size class

Individuals of species with typical maximum bodyweights of < 2 kg were classified as small, individuals of species with typical maximum bodyweights 2 - 5 kg were classified as medium, and individuals of species with typical maximum bodyweights > 5 kg were classified as large, as per the definitions presented in Erena's 2022 study.

Camera trap specifics

The model of all cameras used was Cuddeback IR Model G-5017 Original. Cameras were set to take 3 photo bursts, as in a 2021 study by Pearce et. al, with a thirty second delay, day and night, and used infrared flash at night.

Data Analysis

Transects at Raup's Wildlife Sanctuary were started at the edge of the forest bordering the gravel road, using it as the edge, and extended inwards to the core forest.

Since there are multiple edges at Mammoth run, transects were started in closest proximity to the housing development, and extended inwards towards the core forest, which was arbitrarily designated the primary edge. The grid of cameras was also analyzed as if transects were started closest to the forest and extended towards the road, to determine the differing effects manmade edge and ecotone.

Transects at Greendale Cemetery were started at the forest's edge next to the cemetery, and extended inward, over the ravine, to the core forest on the opposite side.

Data was analyzed using Microsoft Excel. Analysis included total mammal species at points along the transects, in relation to distance from the edge, as well as the locations of individual species in relation to the edge. Trends in detection of particular species across the transect were analyzed to determine whether there was a link between distance from fragment edge and presence of a species or size class of mammal.

The Shannon Wiener diversity index was also used to compare corresponding points on each transect at each plot to other sets of corresponding points (edge points compared to core points). The Shannon Wiener index, as detailed in (Rocchini et al, 2013), is as follows:

$$H(s) = - \sum_{i=1}^s p_i \ln p_i$$

In the equation, $H(s)$ represents the diversity of species within a sample, S represents the number of species in that sample, p_i is the relative abundance of each species (number of individuals of the given species out of the total number of individuals present in the sample), and $\ln = \log$ to base e (natural log). The index also calculates sample evenness, in this case, a composite measure of the relative abundance of all species within the sample. Sample evenness is calculated as:

$$J' = H(s)/H(s)_{\max}$$

In this equation, J' represents the evenness of the sample, $H(s)$ is the diversity within the sample calculated using the above equation, and $H(s)_{\max}$ is the natural log of the number of species within the sample, S .

Detections of members of the same species were considered independent if there was a time gap of twenty minutes or more between the two detections, or if there were clear visual differences between the animals in question (Zlatanova & Popova, 2018). These trends in species presence, richness, and diversity were compared not only within properties, but between the three properties as well. All trends were independently analyzed by site and by individual species, and were tested for statistical significance using a two tailed, unpaired t test, with $p = 0.05$ set as the statistically significant threshold.

Results

Species detected

There were four species detected and 164 independent detections (Table 1). Species detected across all transect points at three sites were white-tailed deer (*Odocoileus virginianus*) (n = 127), northern raccoon (*Procyon lotor*) (n = 19), black bear (*Ursus americanus*) (n = 1), and eastern gray squirrel (*Sciurus carolinensis*) (n = 17).

Table 1. Basic detection data.

Total detections, all species	164
Species detected	4
Species detected by size class	
Small	1
Medium	1
Large	2
Total individual detections by size class	
Small	17
Medium	19
Large	128
Total species detected across all edge and core points	
Edge	2
Core	4

Table 1. Basic species detection and individual detection data for the three survey sites, Raup's Wildlife Sanctuary, Mammoth Run, and Greendale Cemetery. Surveying was conducted from 9/29/2023 to 10/13/2023 at Raup's Wildlife Sanctuary, from 10/6/2023 to 10/20/2023 at Mammoth Run, and from 11/7/2023 to 11/21/2023 at Greendale Cemetery.

White-tailed deer, black bear, northern raccoon, and eastern gray squirrel were found at core points while only white-tailed deer and eastern gray squirrel were found at edge points (Table 1). The survey detected more large mammals (>5 kg) species ($n = 2$) than small (<2 kg) ($n = 1$) and medium (2-5 kg) ($n = 1$), and more large mammal individuals ($n = 128$) than the smaller two size classes (small mammals $n = 17$ and medium mammals $n = 19$), though the differences were statistically insignificant ($p = 0.10$ for edge effect on number of species detected).

Table 2.***Individual detections by site, species and edge status.***

Site	Edge/core	Species	Number of species detections	Total detections
Raup's Wildlife Sanctuary	Edge	White-tailed deer	21	21
	Core	White-tailed deer	27	28
	Core	Black bear	1	
Mammoth Run	Edge	White-tailed deer	7	7
	Core	White-tailed deer	13	28
	Core	Northern raccoon	15	
Greendale Cemetery	Edge	White-tailed deer	23	27
	Edge	Eastern gray squirrel	4	
	Core	White-tailed deer	36	53
	Core	Northern raccoon	4	
	Core	Eastern gray squirrel	13	

Table 2. Individual detections by species and edge status at Raup's Wildlife Sanctuary, Mammoth Run, and Greendale Cemetery. Surveying was conducted from 9/29/2023 to 10/13/2023 at Raup's Wildlife Sanctuary, from 10/6/2023 to 10/20/2023 at Mammoth Run, and from 11/7/2023 to 11/21/2023 at Greendale Cemetery.

In all three sites, there were more species detected and more total detections at core points than at edge points, though the trend was not found to be statistically significant when analyzed by total detections at all three sites ($p = 0.15$), or when analyzed by site ($p = 0.85$ at Raup's Wildlife Sanctuary, $p = 0.1$ at Mammoth Run, and $p = 0.51$ at Greendale Cemetery) (Table 2).

Mammoth Run ecotone

Mammoth Run was the only site with two different types of edge that were too close together to be compared separately. When the field-forest edge is set as the primary edge for analysis, there is a statistically significant edge effect on number of individuals detected ($n = 33$ edge, $n = 4$ core, $p = 0.03$). This was the only statistically significant edge effect observed.

Figure 1.

Shannon Wiener diversity index by site and edge status

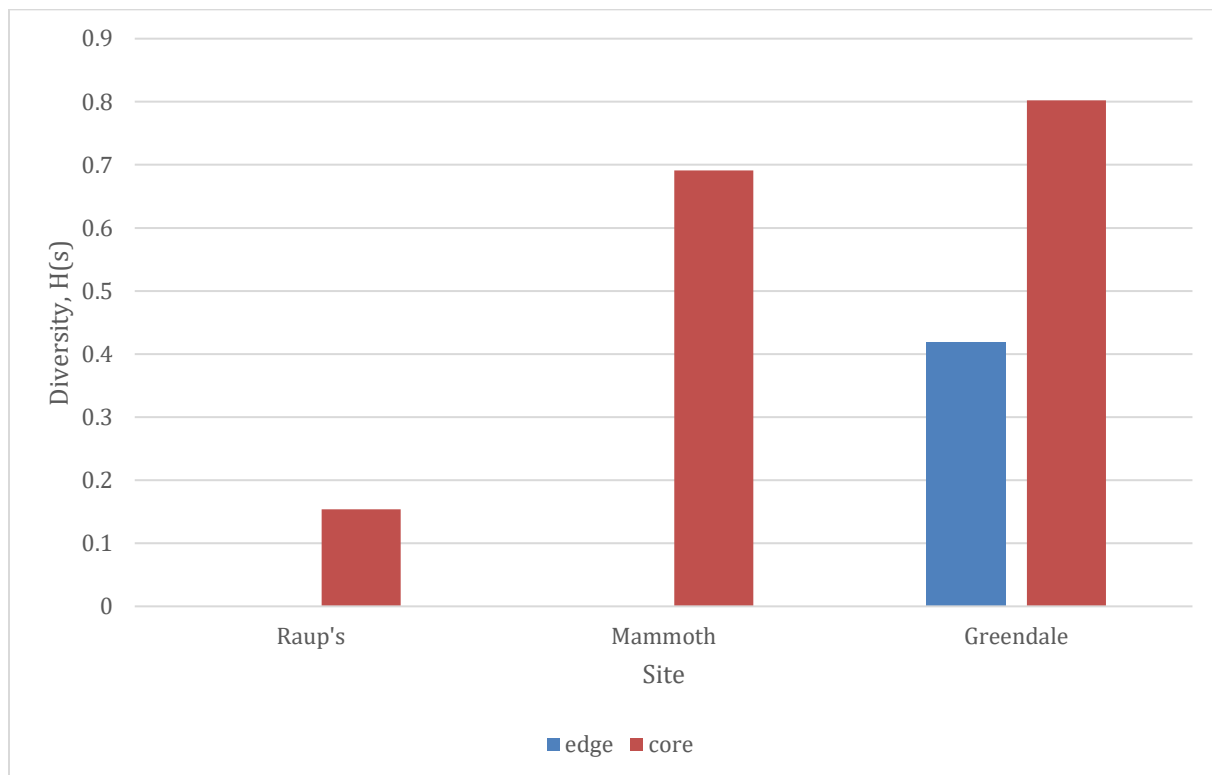


Figure 1. Shannon Wiener diversity index values for Raup's Wildlife Sanctuary, Mammoth Run, and Greendale Cemetery. Surveying was conducted from 9/29/2023 to 10/13/2023 at Raup's Wildlife Sanctuary, from 10/6/2023 to 10/20/2023 at Mammoth Run, and from 11/7/2023 to 11/21/2023 at Greendale Cemetery.

The Shannon Wiener diversity index indicated greater diversity in core points at all three sites, with a 15% increase between edge and core at Raup's Wildlife Sanctuary, a 69% increase for Mammoth run, and a 96% increase for Greendale Cemetery. The trend was not found to be statistically significant ($p=0.17$) (Figure 1).

Figure 2.

Shannon Wiener evenness index by site and edge status

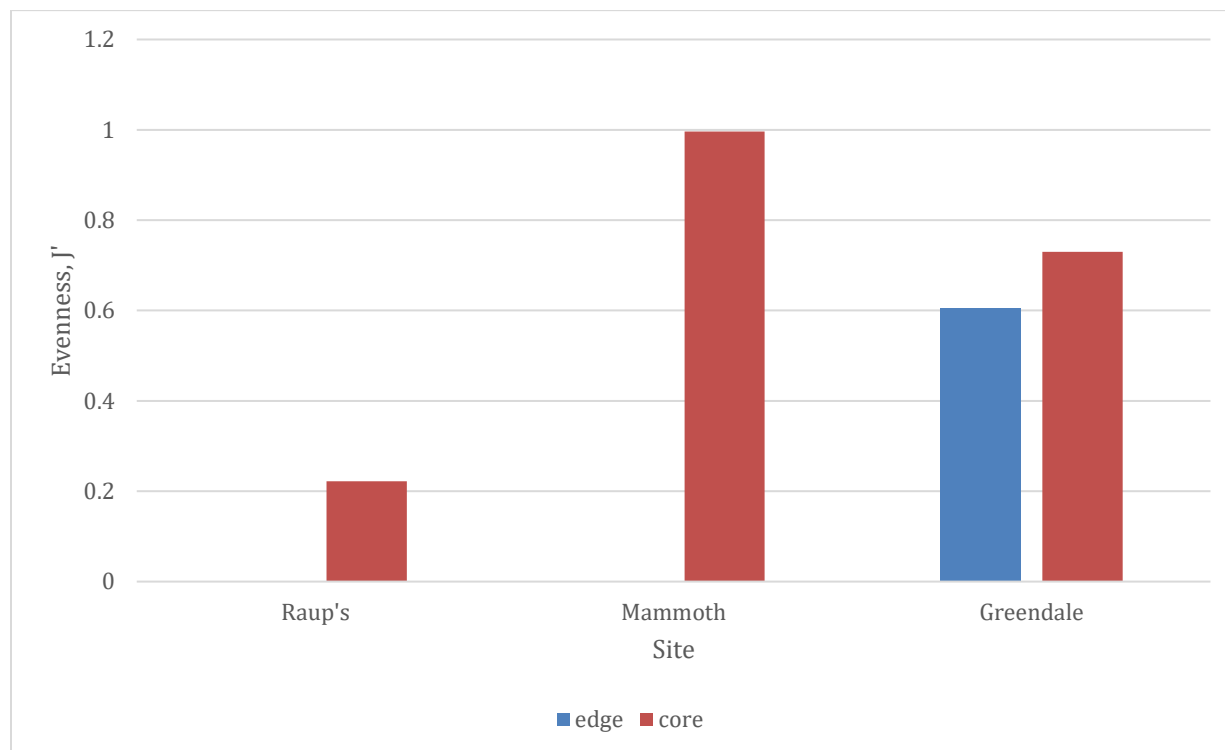


Figure 2. Shannon Wiener Evenness values for Raup's Wildlife Sanctuary, Mammoth Run, and Greendale Cemetery. Surveying was conducted from 9/29/2023 to 10/13/2023 at Raup's Wildlife Sanctuary, from 10/6/2023 to 10/20/2023 at Mammoth Run, and from 11/7/2023 to 11/21/2023 at Greendale Cemetery.

The Shannon Wiener diversity index indicated greater evenness in core points at all three sites, with a 22% increase for Raup's Wildlife Sanctuary between edge and core, a 99% increase for Mammoth run, and a 20% increase for Greendale cemetery. The trend was not found to be statistically significant ($P=0.21$) (Figure 2).

Statistical Significance

Table 2.

Statistical significance of edge effect by measure

Measure	P value
Total species	0.10
Total detections	0.15
Shannon Wiener diversity (Hs)	0.17
Shannon Wiener evenness (J')	0.21

Table 2. Statistical significance of edge effects at Raup's Wildlife Sanctuary, Mammoth Run, and Greendale Cemetery. Surveying was conducted from 9/29/2023 to 10/13/2023 at Raup's Wildlife Sanctuary, from 10/6/2023 to 10/20/2023 at Mammoth Run, and from 11/7/2023 to 11/21/2023 at Greendale Cemetery.

None of the trends in the survey were statistically significant to a threshold of $p=0.05$. There was no statistically significant variance due to edge in total species, total detections, diversity, or evenness (Table 2).

Table 3.

Statistical significance of edge effect by species

Species	P value
White-tailed deer	0.38
Black bear	0.37
Northern raccoon	0.23
Eastern gray squirrel	0.54

Table 3. Statistical significance of edge effect on individual detections at Raup's Wildlife Sanctuary, Mammoth Run, and Greendale Cemetery, analyzed by species. Surveying was conducted from 9/29/2023 to 10/13/2023 at Raup's Wildlife Sanctuary, from 10/6/2023 to 10/20/2023 at Mammoth Run, and from 11/7/2023 to 11/21/2023 at Greendale Cemetery.

None of the detected species showed a statistically significant edge ($p = 0.05$) effect across the three sites (Table 3).

Discussion

There was insufficient evidence to confirm all but one measure of edge effect on mammals at Raup's Wildlife Sanctuary, Mammoth Run, and Greendale Cemetery. It was predicted that man made edges would have the greatest effect on mammal diversity at all three sites due to lack of food and habitat. However, the only statistically significant edge effect detected was the effect of a field-forest transition. It was also predicted that small mammals would show the greatest edge effect, but the observed effect only included medium and large mammals. Effect of ecotones was predicted to be minimal for large and medium mammals, and thus was only included in analysis out of necessity, due to the limited available sites for study. Thus, the research aimed to investigate effects of manmade edges on small, medium, and large mammal diversity, and did not find any, but did find the unexpected result of a natural edge effect on number of detections of medium and large mammals. Further potential for analysis was limited due to the trend only being present in one of three sites, and the fact that while manmade edges were present in all three, an ecotone was only present at Mammoth Run. A further complicating factor is the fact that one of the four survey points at Mammoth Run was located at the corner of both a manmade and a natural edge. For this reason, if future research is to focus on effect of ecotones or on comparing ecotones to manmade edges, studies should be properly controlled by setting survey points at either a manmade edge or a natural one, but not both.

The failure to detect any effect of manmade edges indicates that for similar applications with small properties and limited timeframes, different survey methods should be used. The survey method used was as close as possible to the recommended standards of multiple other camera trap studies, but fell short in a few ways. It was consistent with the two hundred meter even spacing scheme recommended for un-baited cameras by Smith et. al. in their 2022 study, across all sites. In Raup's Wildlife Sanctuary, this only allowed four cameras total to be placed due to the sizes of the properties, and this number was repeated in Greendale Cemetery for the sake of consistency.

The timescale for a camera trap survey, recommended by Kays et. al. in a 2020 metareview, was at least 3 weeks, and the recommended minimum number of cameras was twenty, though two weeks was presented as an absolute minimum. This time length was not met, with each site being surveyed for two weeks instead of three due to time constraints, including seasonality. In the same study, a meta review, there were still some surveys which did not meet the author's recommendations when it came to number of cameras. Due to a comparative lack of camera trap studies in the eastern US being used to create the recommendations, and a complete lack of studies using evenly spaced, un-baited camera traps for a comparative study of edge effect on small, medium, and large mammals, it seemed worthwhile to test the used method. This is especially relevant for the French Creek Valley Conservancy. The FCVC has a

number of small fragments, as well as limited resources and workers. This makes certain survey techniques, such as large-scale camera trap grids with wide spacing, impossible, or others such as radio collaring, prohibitively difficult. The likelihood of a small sample size hampering definite conclusions was predicted to be the primary limitation from the beginning, and that was exactly what was observed.

For future surveys, if camera traps are used, there are a few potential ways to avoid the limitations encountered here. First, the original intent of the survey was to measure mammals of all size classes and make comparisons about edge effect on the species and size class level. Small mammals, especially rodents, often have small home ranges (Howell, 1954), and were thus singled out as ideal study subjects for edge effect. The method used detected too few species for this to be possible, with only one small mammal (which was also a rodent) detected, the eastern gray squirrel (*Sciurus carolinensis*). There was also only one species of medium mammal detected, the northern raccoon (*Procyon lotor*).

Of the large mammals detected, there were only two species, black bear (*Ursus americanus*) and white-tailed deer. As for detections, there was only one bear detection, and 127 independent deer detections. The disproportionate number of deer in the data sample likely skewed results. There were more deer detected by a factor of more than three than all of the other species put together. Since the survey method did not capture enough individuals of other species and other species overall, it is impossible to simply analyze the data with and without deer. One possible explanation for the fact that no statistically edge effects were observed is that deer do not exhibit any edge effects detectable with the given survey method, and that the majority of the sample consisted of deer. This potential factor and the general lack of detections, lack of species richness, and short timescale are not mutually exclusive, and could all have some role in producing the lack of observable trends.

It was clear from numerous photos that animals were aware of human presence, and even of the cameras themselves. Multiple deer came close to the cameras to investigate them, and the black bear even made physical contact with a camera enough to change its orientation. Different animals may have different responses to human presence within their habitat, and while deer and bears may seek out camera traps out of curiosity, other species may actively avoid them. In a European study of mammalian predators, some individuals exhibited behaviors indicative of aversion to camera traps (Meek et al., 2016). Along with short survey time and wide spacing, this may be one factor partially explaining the low number of species detected.

The size and location of the sites used made edge to core comparisons difficult. Sites were selected based on acreage, but all three were still only big enough to support two cameras along a transect running from edge to core, giving just two detection sets just two hundred meters apart. Due to the nature of the three sites chosen, different boundaries constituting edges had to all be treated the same, and different interior landscapes had to be coded as core. This may have had an effect on the detections, but it

is impossible to say without a more comprehensive study involving more sites. At Raup's Wildlife Sanctuary, the edge was a dirt road with a mowed grass yard and a house opposite the forest, and the core was typical western Pennsylvania mid succession hardwood forest that extended for more than 200 meters beyond the property boundary. At Mammoth Run, the edge was a dense housing development, and the core was on one side a forest with a thick shrub layer bordering a meadow, and on the other a patch of standard mid succession hardwood forest with a large semi wooded yard less than 200 meters away in one direction. While the edge was coded as the housing development, there was also a paved road perpendicular to the development, and two of the points, one of them a core point, were about 160 meters away from it, making them close to the required spacing from an edge, but not quite meeting it.

Greendale Cemetery's edge points were set next to a cemetery and a fenced off grass yard. Its core points were both surrounded by unique elevated forest dominated by oaks, beeches, and hemlocks and birches and steep canyons created by a series of spring fed creeks. Between the core and edge points is a large ravine and stands of enormous hemlocks and other old growth trees, some of them state record holders (Helmreich, 2010). The difference between this landscape and the other two could potentially impact animals just as much as proximity to a man-made edge. Comparisons in biodiversity and edge effect between this site and the others were impossible again because no statistically significant trends were found.

Finally, seasonality may have played a role in lack of detection of some species, specifically hibernating mammals. The woodchuck (*Marmota monax*), a medium mammal, and the chipmunk (*Tamias striatus*), a small mammal, hibernate over the winter (Saunders, 1988), with the woodchuck potentially starting in late September at the earliest, though usually in October, depending on the weather. The first survey site, Raup's Wildlife Sanctuary, was surveyed in September, and there was no frost during the two weeks of camera trapping. However, there were cold nights with light frost during the Mammoth Run surveying, though the days were still generally summer like, and there was a heavy snowfall during the Greendale Cemetery surveying. Multiple rodent species, while not true hibernators, exhibit different behavior in cold weather months. This presents one more potential explanation for the lack of species detections during the survey.

Recommendations

Future studies involving camera traps should use a longer survey time of at least three weeks, as an absolute minimum, but ideally longer (Kays et. al, 2020), to make up for the low number of cameras. There were enough detections of deer to justify the use of the method for studies focusing specifically on deer. Beyond this, the idea of a broad, catch-all mammal biodiversity assessment using one spacing and

time scheme of camera traps is likely unrealistic or imprecise. The single observable edge effect did not involve small mammals at all. It is likely that more targeted surveys would uncover distinct edge effects at the species level which would be less observable in an analysis that groups mammal species of different size classes and niches together.

A reasonable starting point for continued research would be a larger study using a similar camera trap survey, following the above recommendations, designed solely to examine effect of field-forest edges on mammal diversity. If the trend is observed across multiple FCVC properties with a wide range of species detections, further detailed analysis aimed at parsing out the edge effects on different groups of mammals would be warranted.

While camera traps may be effective in surveying mammals of all size class when presence is the desired variable, different setups are generally used for different types of mammals (de Bondi, et. al, 2010; Kays et. al, 2020; Pearce et. al, 2021). Using a similar method to mine, one could potentially offset some of the lack of small mammal detections with a longer time frame, but the fact that no mice or shrews at all were detected indicates that it would likely be more efficient to use a more tailored approach. Different survey methods should be used for different types of mammals based on size and home range. Bait could also be warranted for small mammals, and a comparison of camera trap and physical trap effectiveness in the FCVC should be done. If camera traps are to be used, a denser spacing scheme could aid in detection of rodents, as well as lower distance from the ground (Meek, 2016) and close proximity to bait to ensure that the cameras' motion sensors are activated by the smaller animals.

Due to the larger home ranges of medium mammals such as raccoons, it is still reasonable to test the effectiveness of camera traps in studies focusing on them. Increased survey time could potentially capture more medium mammals than just the raccoon, which is likely the most common medium mammal in the region, especially due to the proximity to human settlement of all three studied sites. Common species like virginia opossum (*Didelphis virginiana*), red fox (*Vulpes vulpes*) gray fox (*Urocyon cinereoargenteus*), other species of squirrels (*Sciurus spp*), chipmunk (*Tamias striatus*), cottontail rabbit (*Sylvilagus spp*), and woodchuck could likely be detected with increased time using the already used methods, and are likely present within the FCVC properties.

Different methods should be used for rarer animals and species with specific habitat requirements, such as beavers (*Castor canadensis*) and river otters (*Lontra canadensis*). The coyote (*Canis latrans*) is the most common large predator in the survey area, and was not detected at all. This indicates that baited traps could be more effective at surveying predators, as coyotes, mink, and other predators have comparatively large home ranges, and lower population density (Carnegie Institute, 2017). A more sensitive survey method with deliberately placed baited cameras would be better especially for rarer carnivore species which may or may not be present on conservancy land (Moyer, 2017), such as

various weasel species (*Mustela spp*), fisher (*Pekania pennanti*), and bobcat (*Lynx rufus*), but this is outside the aim of this project anyway.

A basic comparative study of the effectiveness of camera trapping compared to physical trapping for small mammals, especially rodents, should be done in the FCVC if finding efficient survey methods is a priority. If results are similar between the two trap types, then other variables should be considered such as cost to purchase and maintain the traps, ease of setup, setup time, and pack up time. One factor to take into account is the fact that physical traps need to be checked frequently to ensure the safety of the trapped animal. This is not the case with camera traps, where the only maintenance during the trapping window would be rebaiting. The effectiveness of camera traps and physical traps in detecting small mammals in the FCVC will have to be weighed against the amount of work required to do the survey with both trap types. It is still possible that with a different setup, camera traps can still be a useful tool for surveying small mammals, and that the two trap types may both be effective for slightly different study designs both focusing on small mammals.

Man made edge effect is likely still an important dynamic in the FCVC properties. I would recommend first using the same methods used here with a longer time frame to compare ecotone and manmade edges, and simply to determine if more detections can reveal any significant trends at all. It is likely again that large mammals, especially deer, would make continue up the majority of sightings. Deer have large home ranges, and tolerate human settlement, as well as make use of both forest habitat and clearings, so it is possible that within the spatial scale of a single FCVC property, there is no observable edge effect on deer detections. The home range of a deer means that one deer could easily walk anywhere in an FCVC property in a normal day. Consequently, when examining edge effects on deer, even if there was found to be an observable effect, it would only be possible to say that deer spend more time in certain areas, not that they are never present in certain areas, unless a much more intensive survey method was used. This is very different from mammals with smaller home ranges, where if a trend were found, one could confidently conclude that certain species are actually present in greater numbers in a given area than in others. For this reason, I recommend that studies on edge effect in the FCVC be separated by animal home range size as a primary consideration. If there are limited resources available, I would recommend prioritizing small mammals and mammals with small home ranges as study subject before medium and large ones, as with small mammals it is more likely that an edge effect could actually be detected more easily. It is likely that there are species within the FCVC that have specific habitat requirements and small home ranges, such as cottontail rabbits (*Sylvilagus spp.*) and meadow jumping mice (*Zapus hudsonius*), which would show on a survey designed around species with small home ranges.

The survey, while it was intended to provide a broad assessment of mammal diversity within three FCVC properties, only focused on terrestrial mammals. Another potential high value study of mammal biodiversity within the conservancy could focus on bats. Since the conservancy's purpose is to protect biodiversity, it would be in line with this purpose to make bat habitat a conservation goal, especially in light of the falling bat population across the United States (USDA Forest Service, 2022). While the method I used shows some potential value for future studies targeting common species such as deer, raccoons, and squirrels, since these species are likely present all across the landscape outside of the FCVC properties, it may be a better use of resources to focus on species that are less common and less resilient. Deer, raccoons, and squirrels are generally resilient, and less likely to be affected one way or another by the actions of the FCVC, while species that are less resilient and less common could benefit from deliberate conservation action from the FCVC. For example, a land management plan prioritizing snag density could conceivably make a real difference in the bat population of the surrounding area, while there is little the organization could do to affect deer or raccoon populations.

Finally, further studies, if they focus on edge effect and are able to identify trends within a single site, should examine difference in trends between sites, especially focusing on differences in biodiversity and edge effect between different landscape types, e.g. the hemlock ravine forest of Greendale Cemetery compared to the mid succession, flat forest of Raup's Wildlife Sanctuary. Detailed comparisons could be made using a combination of field biodiversity surveys and geographic information systems (GIS). GIS could be used to determine and quantify trends in landscape cover such as ecosystem type, including different types of forest, and comparisons between forest, grassland, and wetland.

Predators

One noteworthy finding of the study was the presence of a black bear. The presence of the species alone is significant, and it could potentially impact deer behavior as well. While black bears are omnivores and do not typically prey on deer, they are *capable* of preying on deer, especially young ones (Pennsylvania Game Commission, 2024; Weaver, 2000). In some cases, behavior of ungulates including white-tailed deer can be altered by the mere presence of a large potential predator (Olson et. al, 2019). Deer over-browsing represents a potential threat to biodiversity within the FCVC (Brozell et. al, 2020), so the potential for bears to alter the browsing behavior of deer could be significant. Bears are present in western Pennsylvania, but not overly common, and are known to be elusive and have large home ranges. For this reason, it is unlikely that a short-term study taking place within a few FCVC properties would be able to gather a lot of information about bears, but simply knowing that a bear has been sighted at a particular location in the conservancy can be added to a larger body of information that can develop over

time. Over time, with increased sightings, the conservancy could get at least a partial idea of which existing properties are more often visited by bears. It is less likely but still conceivable that a bear den could even be found within the conservancy at some point in the future. If there *are* properties frequented by bears, and even local groupings of properties frequented by bears, this could help inform land management decisions and even the acquisition of new properties, if bear habitat were a conservation goal. For any biodiversity-oriented organization, the presence of a relatively uncommon large mammal is significant. The presence of a charismatic large animal such as the black bear also has public relations advantages. The black bear is a relatively well-liked species by wildlife enthusiasts and conservation supporters, and could be used as a potential tool to gain support from the public for future conservation projects. At the same time, there is a subset of the public who likely hold negative associations with bears. This could be a source of future opposition to the conservancy if the FCVC is associated with increasing bear habitat. In the case of bear proponents and critics alike, though, information about where the bears are within the area would help deal with both the opportunities and challenges posed by different slices of the public.

Also noteworthy is the fact that no coyotes were detected in the survey. Coyotes are, other than the bear, the largest predator in the study region. They are also key predators of small mammals (Carnegie Institute, 2017; Brewster, 2017) and capable of killing young deer, and on rare occasions even mature deer, and thus have far reaching effects on the ecosystem. A New York study found that presence of coyotes can impact deer browsing behavior (Pierce et. al, 2015). Coyotes, like bears, have a mixed reputation. They are seen by some, particularly livestock farmers, as a pest and a source of danger to their animals (Weaver, 2000). In many cases, coyotes' destructive potential and overall prevalence in a landscape are overestimated by the public, leading to misinformed negative perceptions (Brewster, 2017). For this reason, having some understanding of coyote prevalence within FCVC properties could be important for public relations. Understanding coyote prevalence could also help the conservancy's general understanding of biodiversity within the properties, especially taken alongside measures of populations of other animals that could be coyote prey. For example, if small field dwelling rodents are extremely uncommon at a particular site, but there are few coyotes, this has different implications for land management than if the lack of small rodents is associated with a high prevalence of coyotes. It is possible that with the previously used camera trap scheme, coyotes could be detected with a longer timescale. However, more efficient survey methods designed specifically for coyotes would be ideal. If trends regarding edge effect on small mammal diversity were to be determined, the implications would be less clear without corresponding data on predation. This even applies to deer browsing, which as mentioned, is a major ecosystem dynamic in the region and a potential threat to biodiversity within the

FCVC. Based on this, it seems warranted to investigate whether coyote presence has any effect on deer behavior within the FCVC, especially given that it has been shown to do so in a nearby state.

Conclusions

The two-week, 200 meter evenly spaced, un-baited camera trap survey was able to detect any effect of manmade edges on small, medium and large mammal diversity in western Pennsylvania forest fragments. It did, however, uncover a potentially more significant effect of field-forest edges on deer and raccoon detections, and presented a number of new research questions. The survey did not detect many species, and most individuals detected were white-tailed deer, but even among white-tailed deer, of which there were over 100 detections across three sites, no statistically significant edge effect at all was observed when analyzed at the species level. This highlights the potential large numbers of deer detections to bias future surveys that focus on groups of species, and the need for more precise studies. The idea of a time and resource efficient survey method that accounts for two important ecosystem dynamics at once, edge effect and mammal diversity, remains tempting, but resources could likely be better used on multiple, more specific surveys. With the method and aim tested, at least, the tradeoff of sacrificing precision for efficiency and a broad set of data did not pan out. This does not entirely rule out the possibility of such a survey being possible, but this particular set of methods have not been shown effective for their intended purpose. It has, however, indicated a set of potentially valuable baseline biodiversity surveys that could be conducted moving forward.

For medium and large mammals, with a greater timescale and potentially with more sites, there is reason to believe that the camera trap scheme could be more useful. It remains to be seen whether the lack of manmade edge effect observed was simply because the species observed are not affected by edges on the spatial scale of the FCVC properties, or because there was not sufficient data. For small mammals, an alternative method should be used, including a comparison between baited camera traps with an alternative spacing scheme and physical traps.

It is still likely that mammals in the FCVC experience some manmade edge effects, and that determining these effects is still an efficient use of resources due to the scale of fragmentation in the region and in the FCVC. The final questions entail comparing manmade edges to natural edges, based on the edge effect of the field-forest transition observed in Mammoth Run. This result indicates multiple clear paths for future research. Follow up studies will ideally be able to identify more significant trends in biodiversity and edge effect using some of the methods recommended here, which can help inform conservation efforts by the FCVC in the future.

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