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Smile For the Camera: Patterns of Mammal Abundance in  
Great Hill Forest Through Four Years of Camera Trapping

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Submitted in Partial Completion of the Requirements for  
Commonwealth Honors in Biological Sciences

Bridgewater State University

May 9, 2023

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Date: 5/9/2023

**Smile For the Camera: Patterns of Mammal Abundance in  
Great Hill Forest Through Four Years of Camera Trapping**

Alexander Gonatas

**Abstract**

Snapshot USA is a nationwide camera trapping project aiming to determine biodiversity and abundance of animal populations across all 50 states. Since 2019, participants have used camera traps to document wildlife every September and October, coinciding with animal activity patterns and North American academic year starts. Understanding biodiversity through long-term monitoring is an important topic to study, because the knowledge obtained can help track populations and better understand wildlife responses to disturbances. Since Snapshot USA participants use the same methods and trapping season, the information we collect can be directly compared to other Snapshot USA locations. At Great Hill Forest in Bridgewater, MA, our Snapshot USA array has used 8-10 unbaited cameras each year, spaced at least 100 meters apart, during September and October, starting in 2019 and continuing to present. For this study, we are focused on four years of data on wild mammals (humans, domesticated mammals, and birds were removed from the data set). We estimated relative abundance for each species detected using a relative abundance index (RAI), and explored the changes in RAI over time. Over four years, we detected 15 species of terrestrial mammals. Most species were detected every year, however one species (striped skunks) were only detected in one year (2020). Our most abundant mammal was the eastern gray squirrel and in all four years, eastern gray squirrels, eastern chipmunks, and white-tailed deer were consistently the top three most abundant species. Interestingly, gray fox abundance was high in 2019 and 2020, but nearly zero in 2021 and 2022,

while red fox showed the opposite pattern. This suggests replacement of gray foxes by red foxes, perhaps due to competition for food. This thesis documents these and other patterns in mammal abundance at one location, and we have outlined several potential follow up studies: (1) to compare the patterns at our site to other Snapshot USA locations within New England to check for consistency; (2) generate hypotheses to explain the fluctuating patterns we uncovered, and test those using ecological modeling approaches. (3) explore local patterns of seasonal abundance using the larger Bridgewater data set of continuous camera trap monitoring since September 2019.

## **Introduction**

Functioning ecological communities are integral to animal survival. Each species serves a different role, and may depend on different areas of the environment for their home. Murine rodents native to Chad, for example, make use of a wide variety of locations to support their needs, ranging from places with clay-like soil to forests with high canopies (Granjon et al. 2004). From these interactions, successful ecological communities develop. Community ecology tools, like measures of diversity and abundance, are one of the most efficient methods to track species interactions by permitting the researcher to be able to analyze multiple interactions at once, allowing for concise and inclusive findings (e.g., Mansoldo et al. 2022). Thanks to new technologies and perspectives, community ecology research for animals has matured in the past half-century (O’Connell and Hallett 2019). A group of animals that is of particular interest to community ecologists is the class Mammalia, or mammals.

Mammals are an important part of the world’s ecosystems, as these systems would not function properly without them. They are often at the top of food chains, and it is common to

find many mammals co-inhabiting an area, from squirrels and raccoons to larger species like bears (Ikeda et al. 2016). Their lifestyles, diets and habitats are widely diverse, and their physiological and ecological requirements must be met for their populations to prosper. Local mammals to the northeastern United States, such as the eastern cottontail rabbit (*Sylvilagus floridanus*), for example, would not thrive if their habitats did not include low vegetation to feed on and forests with an overstory canopy cover of 58% or greater to protect them from predators (Buffum et al. 2015). Mammals can also play unexpected, yet positive, roles in nature, like the role that small, grazing rodents play in ridding low-salinity marshes of invasive, dominant plants such as *Phragmites australis* through consumption (Gedan et al. 2009). In recent years, however, numerous threats have negatively impacted the biodiversity of mammal communities and their habitats (Davis et al. 2018). Such threats include climate change, natural disasters, and human-related disturbances (Frey et al. 2017). For example, during the recent Australian wildfires, nearly 90% of all native land mammals became threatened (Santos et al. 2022). As such, understanding mammal community structure has proven vital to avoid a potential disturbance or extinction.

Camera trapping is a widely-used method of studying animal populations. Using motion- and/or body heat-activated cameras placed throughout a designated area, accurate animal presence data can be obtained without continuous observation by researchers. Furthermore, camera traps allow researchers to both observe rarely-seen species (Tobler et al. 2008) and study the behaviors of both common and rare species (Rowcliffe et al. 2014). In Tobler et al. (2008), the authors were able to photograph the common lowland tapir and the rare southern naked-tailed armadillo through usage of Deercams, and Rowcliffe et al. (2014) documented behaviors of mammals native to Panama, such as the ocelot and red brocket deer.

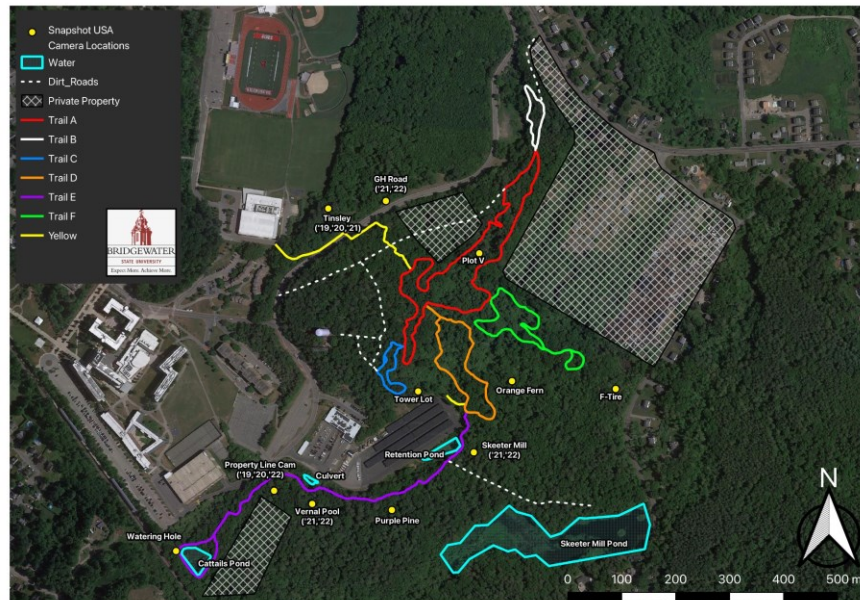
Snapshot USA is a national collaborative camera trapping project led by researchers at the Smithsonian Institution and North Carolina State University (Cove et al. 2021, Kays et al. 2022, Shamon et al. *in review*). Participants in all 50 states follow the same protocol to camera trap at least 400 camera nights per camera array during September and October of each year. The project began in 2019 and continues to present. One goal of this nationwide study is to create a better understanding of animal biodiversity and population trends across the country. Bridgewater State University (BSU) has been part of the project since its start, with continuous camera trapping data dating back to September of 2019.

For this study, we will analyze four years of mammal-focused Snapshot USA data from Great Hill Forest, the wooded area surrounding BSU. We will be searching for patterns and trends in the abundance and diversity of BSU's resident terrestrial mammals. Have individual populations increased since 2019? Decreased? Have some species only appeared in certain years? Have related species taken the place of their relatives? At the beginning of our study, we hypothesized that there may be changes in mammal population trends due to two primary external factors: extreme weather and human activity. Over the four-year trapping period, Great Hill Forest has experienced several fallen trees and windstorms, both of which can have an effect on animal populations (Leśniewska and Skwierczyński 2018). During the COVID-19 pandemic in 2020 and early 2021, many humans and their domesticated animals (i.e., dogs) spent more time on the trails than in 2019 (Burton et al. *in review*). The additional human presence could lead to animals feeling unsafe to roam around during daytime, and lead to changes in behavior or abundance. With these factors in mind, we explored changes in abundance and occupancy for all wild mammals in Great Hill Forest between 2019–2022.

## Methods

### *Description of Field Site*

Great Hill Forest is the wooded area located on the east side of the BSU campus (Fig. 1). Covering roughly 60 acres, it is home to a wide variety of trees, ranging from deciduous trees like oak and beech to coniferous specimens like white pines. It is adjacent to Bridgewater State Forest, another protected wooded area. The forest can be accessed by both BSU students and visitors, as it is a recreational area with numerous hiking trails for anyone to enjoy (Fig. 1). Equipment such as climbing walls and balance beams can also be found along the Great Hill trails. Though the forest is primarily dominated by deciduous trees, the northeast section of Trail A transitions to a more conifer-dominant area (Fig. 1), and the southeast section of Trail F is well-mixed between deciduous and coniferous trees.



**Figure 1:** Map of Great Hill Forest showing trails (colored lines) and camera trap locations (yellow dots).

### *Camera Array Setup*

Our camera trapping array used eight to ten cameras during September and October of each year from 2019-2022. Each camera was placed 0.5 meters off the ground and was not baited. Camera locations are indicated on the map with yellow dots (Fig. 1). Using infrared (IR) and motion-detection technology, the cameras were programmed to instantly take three photos of whatever warm-bodied object in motion would pass by them. Data was collected from the cameras and uploaded to either eMammal (2019; 2020) or Wildlife Insights (2021; 2022; <http://wildlifeinsights.org>) for animal tagging to the lowest taxonomic level and data management. On eMammal we tagged animals manually. Wildlife Insights uses artificial intelligence to do preliminary tagging, so we checked those, and fixed any tagging errors.

#### *Data Cleaning and Analysis*

After tagging was complete, we compiled and cleaned four years of Snapshot USA data to only analyze wild terrestrial forest mammals (e.g., squirrels, chipmunks, skunks, foxes, and deer). Cleaning involved removing records of domesticated animals like cats and dogs, as well as humans were prior to analyses. We also removed birds, as they are not mammals and only make up a small fraction of the photos we captured, and unidentifiable animals, like small rodents or blurry photos.

All analyses were conducted and figures were constructed using R ver. 4.0.2 (R Core Development Team 2020), RStudio ver. 2022.12.0+353 (RStudio Team 2022), and the scripts described in Rovero and Spitale (2016). We estimated several metrics of animal abundance, diversity, and activity across the four years to explore patterns in our data. First, we estimated a relative abundance index (RAI) for each species in each year, which reflects how common a species is in the forest. RAI is calculated by dividing the cumulative number of observations per



hour of a given species by the total number of camera days in the year (number of cameras \* days deployed; Rovero and Spitale 2016). We also used the cumulative number of observations per hour to estimate Shannon's Diversity Index (Shannon 1948) for each year. Second, we estimated naïve occupancy, which reflects how widespread a species is within the whole forest. Naïve occupancy is calculated as the number of cameras a species was captured on divided by the total number of cameras deployed in that year (Rovero and Spitale 2016). We then averaged RAI and naïve occupancy across all four years. Third, we constructed species-accumulation curves to visualize how quickly we captured the maximum species in a given year.

For the six most common species (i.e., highest average RAI), we constructed activity clock figures to visualize the activity patterns of these species and detect any notable changes across the years (Rovero and Spitale 2016). We also constructed a cumulative activity clock for these same species which included all observations across all four years.

## **Results**

The species with the highest relative abundance index was the eastern gray squirrel (*Sciurus carolinensis*; Table 1). White-tailed deer (*Odocoileus virginianus*) and eastern chipmunks (*Tamias striatus*) were a distant second and third (Table 1), however these three species were much more abundant than all other species detected (Table 1). The three species with the lowest RAI numbers were striped skunk (only seen in 2020), small weasels, and groundhogs (Table 1). When plotting average RAI by species, eastern gray squirrels, eastern chipmunks and white-tailed deer had to be removed because their RAI values are much larger than every other species (Fig. 2). Eastern gray squirrels and white-tailed deer also showed high naïve occupancy (i.e., proportion of cameras in the array which detected a species; Table 1; Fig.

3), however eastern chipmunks showed lower naïve occupancy, suggesting there are areas of the forest they are not using (Table 1; Fig. 3). When plotting the annual RAI values, eastern gray squirrels were appearing at such a high interval, every other animal's data appeared low and identical (Fig. 4). Annual patterns in RAI were only identifiable once gray squirrels, white tailed deer, and eastern chipmunks were removed (Fig. 5). Over the course of the four years, annual species richness was between 12 and 14 (Table 2), and we recorded 15 unique species overall (Table 1). After around 200 camera nights, we had detected the majority of total species at the cameras, and each year recorded between 504-613 total camera nights (Fig. 6). Species richness was at its highest in 2019 and 2021 and at its lowest in 2022 (Table 2). Similarly overall diversity was highest in 2019 and 2021 and lowest in 2021 (Shannon's Diversity Index; Table 2).

Eastern chipmunk and white-tailed deer showed an alternating pattern of abundance over the four years (Fig. 7). Similarly, the two species of fox, red fox (*Vulpes vulpes*) and gray fox (*Urocyon cinereoargenteus*) showed a 2-year alternating pattern. During the first two years of the survey (2019–2020), gray foxes were much more common than red foxes (Fig. 8). However, in 2021, red foxes became more common, and gray fox sightings began to decline, and in 2022, red foxes were the sole fox species observed in the woods (Fig. 8).

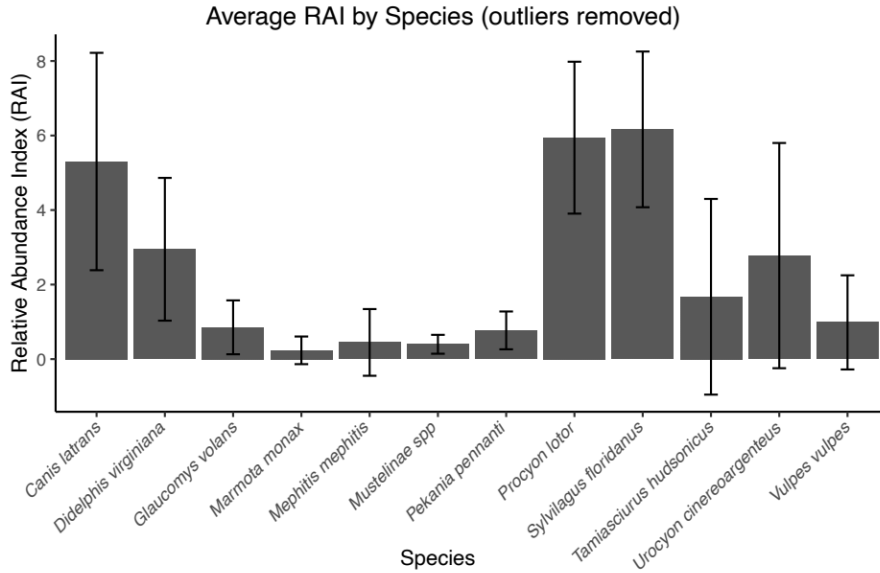
Activity patterns for the most abundant species reveal that generally eastern chipmunks and eastern gray squirrels are diurnal, northern raccoons and eastern cottontails are nocturnal, white-tailed deer are crepuscular, and coyotes show both crepuscular and nocturnal patterns (Figs. 9–10). During 2019, eastern chipmunks were equally active during nearly every daylight interval (Fig. 9A), though this would change in the following years, becoming less active in 2020 and 2022 while gaining nearly even distribution of daylight hours in 2021. (Figs. 9B–9D).

Northern raccoons, though mainly a nocturnal animal, experienced some sightings during daylight cycles in 2021 (Fig. 9C) and 2022 (Fig. 9D).

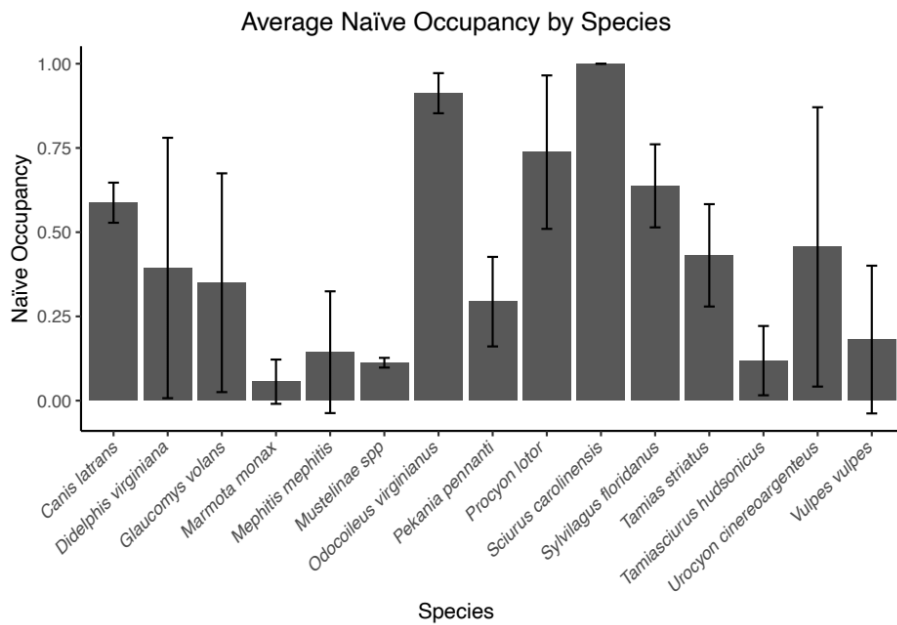
**Table 1:** Average relative abundance index (RAI) and naïve occupancy for all species documented in Great Hill Forest during September and October, 2019-2022. Annual RAI and naïve occupancy were estimated for each species and averaged across all four years. Annual RAI was calculated by dividing cumulative events per hour for each species by total number of camera trapping days in that year.

Species	Average RAI	Standard Deviation RAI	Average Naïve Occupancy	Standard Deviation Naïve Occupancy
eastern gray squirrel ( <i>Sciurus carolinensis</i> )	117.36	33.93	1.00	–
white-tailed deer ( <i>Odocoileus virginianus</i> )	23.05	8.16	0.91	0.06
eastern chipmunk ( <i>Tamias striatus</i> )	18.92	8.36	0.43	0.15
eastern cottontail ( <i>Sylvilagus floridanus</i> )	6.17	2.09	0.64	0.12
northern raccoon ( <i>Procyon lotor</i> )	5.94	2.04	0.74	0.23
coyote ( <i>Canis latrans</i> )	5.30	2.92	0.59	0.06
Virginia opossum ( <i>Didelphis virginiana</i> )	2.95	1.91	0.39	0.39
gray fox ( <i>Urocyon cinereoargenteus</i> )	2.78	3.02	0.46	0.41
American red squirrel ( <i>Tamiasciurus hudsonicus</i> )	1.67	2.62	0.12	0.10

red fox <i>(Vulpes vulpes)</i>	0.99	1.26	0.18	0.22
southern flying squirrel <i>(Glaucomys volans)</i>	0.85	0.73	0.35	0.32
fisher <i>(Pekania pennanti)</i>	0.77	0.51	0.29	0.13
striped skunk <i>(Mephitis mephitis)</i>	0.45	0.89	0.14	0.18
small weasels <i>(Mustelinae spp.)</i>	0.40	0.25	0.11	0.01
groundhog <i>(Marmota monax)</i>	0.23	0.37	0.06	0.07



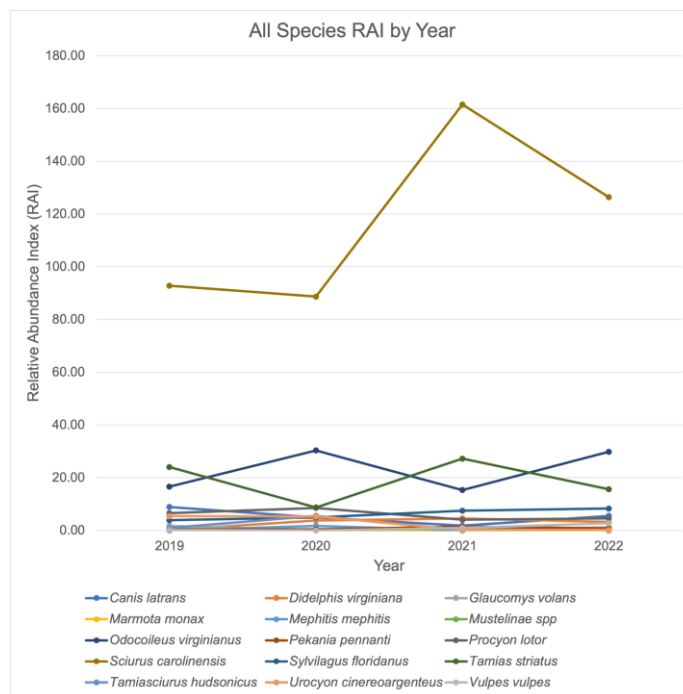
**Figure 2:** Average RAI numbers by species, with outliers removed. Eastern gray squirrels, eastern chipmunks and white-tailed deer have been removed due to their RAI values being significantly larger than all other species documented.



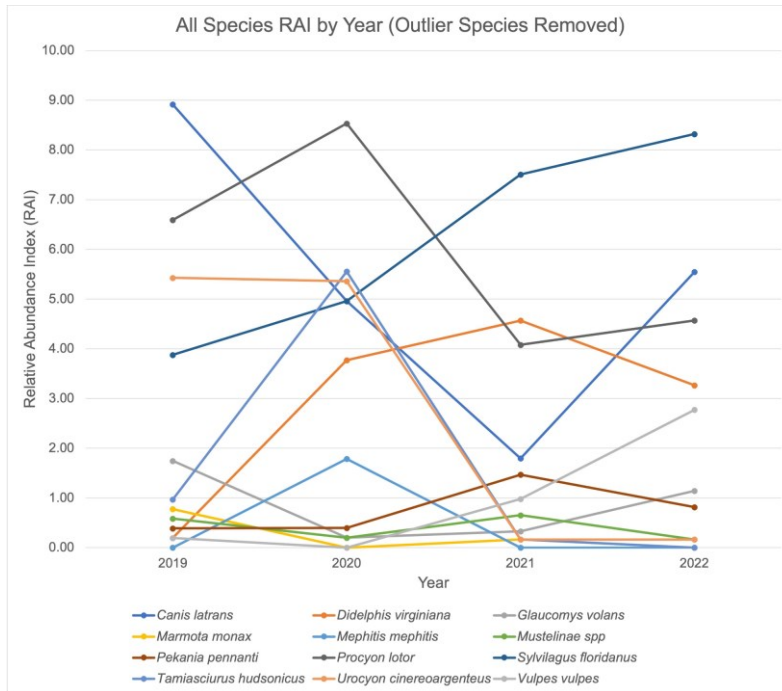
**Figure 3:** Average Naïve Occupancy by Species. Numbers indicate how common a species is in the whole forest as a proportion of the number of cameras which detected that species. A value of 1 means that species was detected on all cameras, and a value of 0.1 (seasons with 10 cameras) or 0.125 (seasons with 8 cameras) means that species was only detected on a single camera.

**Table 2:** Summary of overall diversity. Fifteen unique species were documented during September and October of 2019 – 2022. Annual species richness ranged from 12-14 species. Annual Shannon’s Diversity indices were calculated using cumulative events per hour for each species in that year.

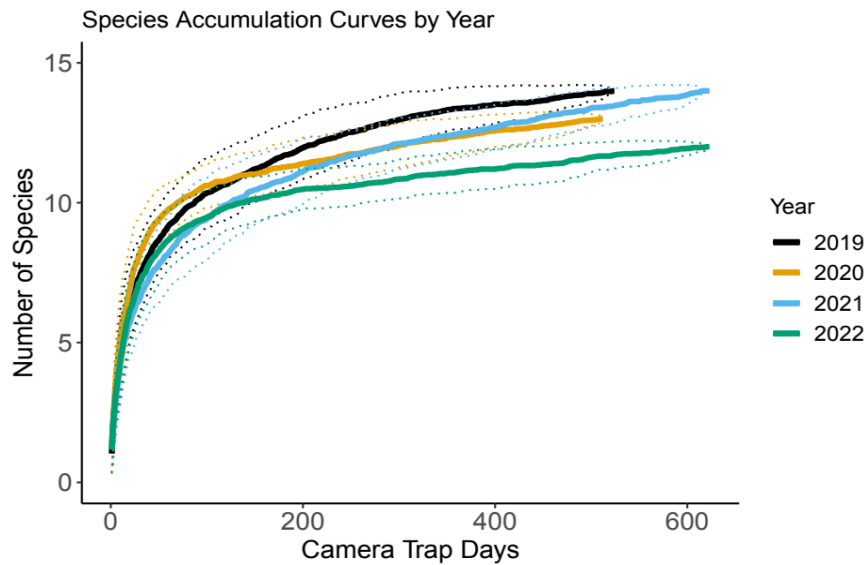
Year	Species Richness	Shannon’s Diversity Index (using species events per hour)
2019	14	1.481
2020	13	1.561
2021	14	1.079
2022	12	1.283



**Figure 4:** Annual Relative Abundance Index (RAI) for all species. The most common species was the eastern gray squirrel (*Sciurus carolinensis*) as, even in the years of lower-recorded presence, it still scored much higher than other species discovered. Other outlier species include the eastern chipmunk (*Tamias striatus*) and white-tailed deer (*Odocoileus virginianus*), resulting in other species appearing less distinguishable once they are factored in.

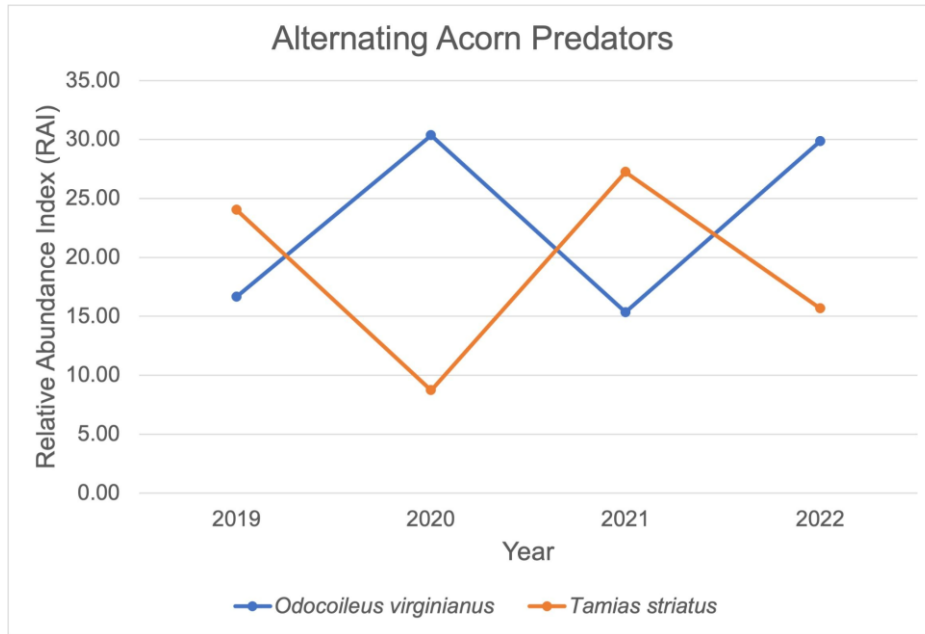


**Figure 5:** RAI of all species by year, excluding outliers. Removal of eastern gray squirrel (*Sciurus carolinensis*), eastern chipmunk (*Tamias striatus*), and white-tailed deer (*Odocoileus virginianus*), revealed annual patterns for the remaining species.

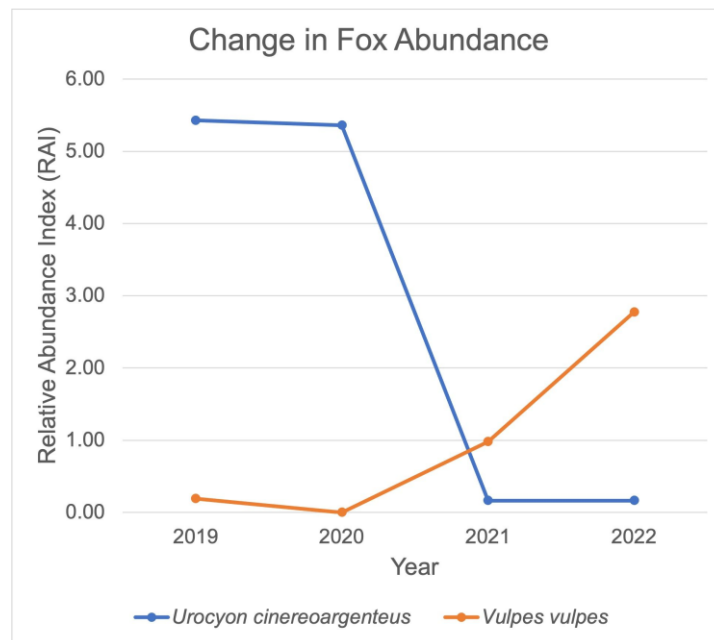


**Figure 6:** Species accumulation curves by year. Dotted lines represent the standard deviation, with each year in a different color. Accumulation across years was similar, with the majority of species being detected after 200 camera trap nights.

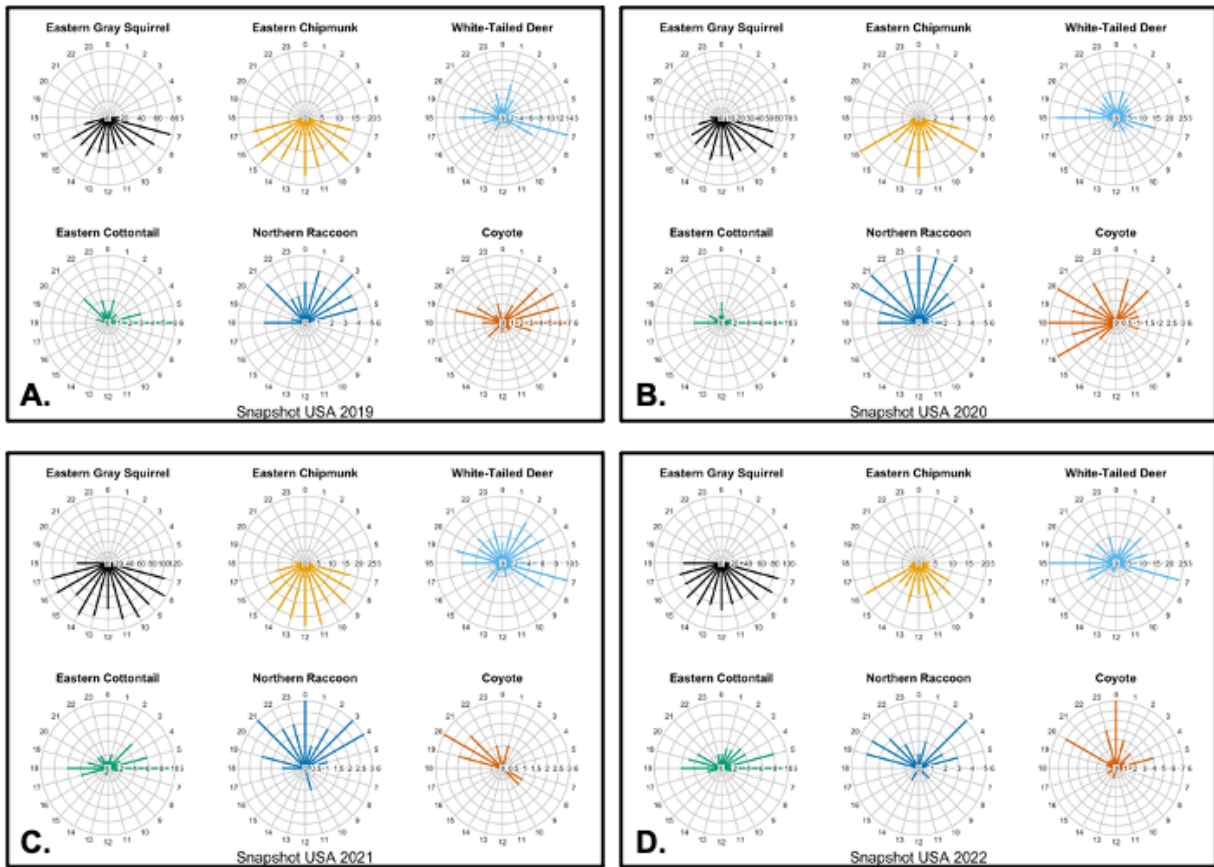




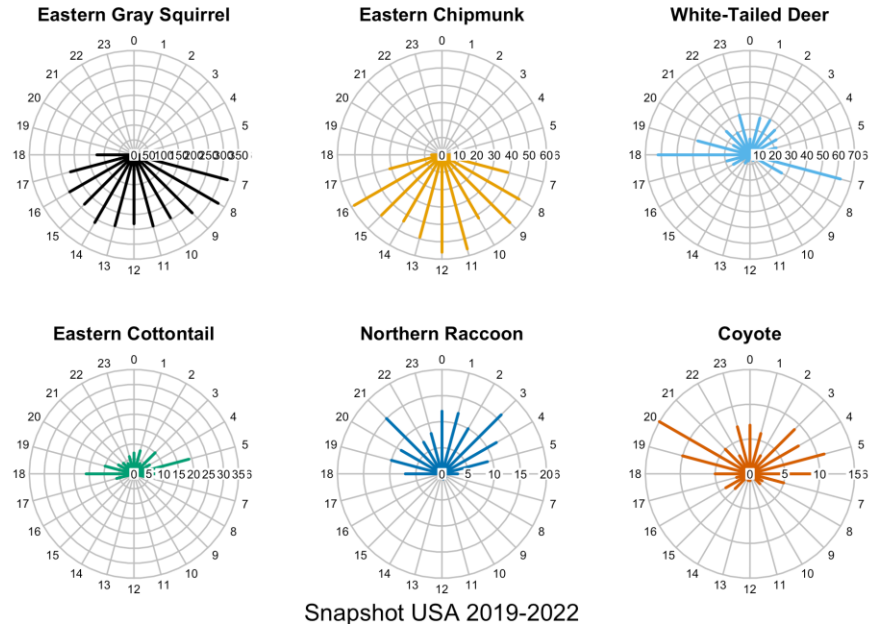
**Figure 7:** Alternating acorn predators. Eastern chipmunks (*Tamias striatus*) and white-tailed deer (*Odocoileus virginianus*) are two of the most prominent consumers of acorns in Great Hill Forest. For every year one species experienced a high RAI number, the other experienced a low one, with a possible explanation for this trend being a shared diet and competition over available acorns.



**Figure 8:** Change in fox abundance over four years. Great Hill Forest has two fox species, the red fox (*Vulpes vulpes*) and gray fox (*Urocyon cinereoargenteus*). In 2019 and 2020, gray foxes were the dominant fox species present, but in 2021 and 2022, red fox were the dominant fox species present, suggesting competition cycles.



**Figure 9:** Activity patterns of most abundant native mammals in each year. Graphs are displayed as if they were a 24-hour clock, with the line length determining how many photographic events were detected at that hour. The top half of each clock represents daytime (6:00 AM - 6:00 PM) and the bottom half of each clock represents night time (6:00 PM - 6:00 AM). A. 2019, B. 2020, C. 2021, and D. 2022. Across the four data collecting years, most of the species patterns stayed relatively similar. However, broad differences were found in the coyote and northern raccoon activity patterns. The former became more nocturnal each year since 2019 (eventually being only detected during night hours in 2022), and the latter began to show slight diurnal activity in 2021 and 2022, after only showing constant but irregular nocturnal during the first two years.



**Figure 10:** Cumulative activity patterns of most abundant native mammals all four years (2019-2022), with the line length determining how many photographic events were detected at that hour. Compared to the annual year data, the cumulative results are similar, with some exceptions. Net coyote data is nearly entirely nocturnal, despite prominent diurnal and crepuscular patterns in 2019 and 2020 (Fig. 9A-9B). The brief daylight intervals detected in 2021 and 2022 for northern raccoons are still present but do not appear on the cumulative figure, suggesting they are outlier events (Fig. 9C-9D).

## Discussion

At the end of the survey, we found that the mammalian species richness of Great Hill Forest reached its highest point in 2019 and again in 2021, while reaching its lowest point in 2022 (Table 2). Shannon's Diversity Index numbers remained similar across the four years, peaking in 2020 and reaching their lowest point the following year (Table 2). Looking at average RAI (Table 1), the six most abundant species were the eastern gray squirrel, eastern chipmunk, white-tailed deer, northern raccoon, eastern cottontail, and coyote. These richness, diversity numbers, and trends are similar to other sites in Massachusetts, and fit with Grade et al.'s (2022) findings that suburban forests in Massachusetts show high terrestrial mammal diversity for our region. Our study did uncover several interesting patterns regarding species interactions and behavior, setting the groundwork for potential future studies.

Annual RAI results showed a zigzag-shaped pattern between white-tailed deer (*Odocoileus virginianus*) and Eastern chipmunk (*Tamias striatus*; Fig. 7). In 2019 and 2021, the Eastern chipmunks' RAI numbers were at their highest, while the white-tailed deer RAI numbers were much lower (Fig. 7). However, in 2020 and 2022, the opposite happened. White-tailed deer RAI numbers climbed to the highest point recorded, and Eastern chipmunk RAI numbers sunk to their lowest points (Fig. 7). These results show that for every year one species experienced a high RAI number, the other would experience a low number, and vice versa. One potential cause of this pattern is acorn predation and competition over food sources, as both animals are known to be acorn predators and have been shown to compete for food in other wooded areas, leading to similar alternating patterns (McShea and Schwede 1993).

One of the most striking changes over the four years was the disappearance of gray foxes, and their near-complete replacement of them by red foxes (Fig. 8). When the survey began, gray

foxes were essentially the lone species of fox being picked up by the cameras. As time passed, red foxes began to slowly take their place, and became the only fox species detected in 2022 (Fig. 8). The exact reason for the change is unknown, but factors such as competition for food and declining gray fox populations (Morin et al. 2022) could be contributing. The alternations between these two species may also be due to these species sharing the same food sources (Hockman and Chapman 1983; Masters and Maher 2021), or differential responses to disease (Kelly and Sleeman 2003). Although gray fox did not make any appearances in 2022, preliminary data for 2023, collected after this project, appears to indicate that the gray fox is coming back and the red fox is again becoming scarce (M.C. Fisher-Reid, *personal communication*).

Activity clock figures allowed us to visualize changes in animal activity for the most abundant species (eastern gray squirrel, eastern chipmunk, northern raccoon (*Procyon lotor*), white-tailed deer, eastern cottontail, and coyote (*Canis latrans*); Table 1; Fig 9–10). Activity patterns varied between years. In 2019, northern raccoons and eastern cottontails were purely nocturnal (Fig. 9A). For the following year, northern raccoons remained nocturnal but became much more active (Fig. 9B), activity for eastern cottontails diminished greatly and they became slightly crepuscular (Fig. 9B). Eastern cottontails maintained a similar activity pattern in both 2021 and 2022, while northern raccoons had some daylight activity reported in those years (Figs. 9C–9D). Data on coyotes was some of the most erratic in the entire experiment (Fig. 9–10), possibly due to recent environmental changes, which have led to larger-bodied mammal communities changing their lifestyles and diets in the past (VanBuren and Jarzyna 2022). Human activity may also play a role in the changes in coyote activity. Burton et al. (*in review*) has shown across Snapshot USA sites that the increase in human activity in wild spaces during the 2020

COVID-19 pandemic led to increased nocturnality among mammals generally, and for carnivores like coyotes in particular.

## **Conclusions and Future Work**

Biodiversity studies are more than just revealing the secret lives of animals, they are the key to understanding and preserving populations. After four years of camera trapping Great Hill Forest mammals, there are several directions to take the study next. The patterns uncovered at our site should be compared to other Snapshot USA locations in the northeast to determine consistency and explore drivers. Once uploaded and compared, we can begin to form hypotheses explaining why the patterns we uncovered look the way they do, and if they align with or differentiate from the findings of others. These will be tested using ecological modeling approaches (e.g., Poggiato et al. 2021). Finally, as we have also collected a larger camera trap data set of continuous trapping since September 2019, we hope to explore these data to better understand seasonal abundance of mammals in the Bridgewater area.

## **Acknowledgements**

This project was funded in part by the BSU Office of Undergraduate Research's Adrian Tinsley Program (ATP) Summer Research Grants to A. Gonatas in 2022, and to S. King and D. Rezendes in 2020. Additionally, several former students of M.C. Fisher-Reid received ATP Semester Grants which contributed to our lab's camera trapping equipment and maintenance. Further support was provided by the Department of Biological Sciences and the BSU Center for the Advancement of Research and Scholarship to M.C. Fisher-Reid, and from the Honors Program to A. Gonatas. The authors would also like to thank the following individuals: Great

Hill Trails manager Dan Rezendes, Roland Kays, William McShea, Michael Cove, Maria Armour, Merideth Krevosky, Kacey O'Donnell, Jenny Shanahan, Ken Adams, Kathy, Dean, and Jason Gonatas, Blake Page, Audrey Lawrence, Grace Leopold, Morgan Cadd, Mohamed Diagne, Shaelyn Donovan, and Denise and Peter Palermo.

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