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Predicting Range Shifts for the Virginia Opossum in Maine

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PREDICTING RANGE SHIFTS FOR THE VIRGINIA OPOSSUM IN MAINE

by

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ABSTRACT

Species distribution and movement are increasingly influenced by climate change and human expansion. The Virginia opossum (*Didelphis virginiana)* has been observed expanding their range northward due to the warming temperatures and urbanization. The Virginia opossums' northern range is thought to be restricted by two abiotic winter factors, snow cover and low temperatures, which prevents foraging and ultimately leads to starvation. For this study, I predicted the movement of the Virginia opossum northward into central Maine and beyond based on current climate change trends. Microclimate temperatures were recorded using data-loggers and climate variable datasets were used to determine if the climate conditions permit establishment of stable opossum populations. The trends in the climate data suggest that central and northern Maine's climate will continue to become favorable for stable populations of the Virginia opossum. The establishment of more suburban areas will positively affect the species' expansion. As a new addition to the biodiversity of central Maine, the opossum's impact on the environment is important to understand. Virginia opossum can be a pest and vector of disease; however, the species also has the capacity of benefiting new environments by being an important prey and a predator of ticks. Predicting how species distribution will change due to the rapid rate of climate change and urbanization can give insight on a species movement into new areas and how their arrival will affect the environment.

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INTRODUCTION

The Virginia opossum's (*Didelphis uirginiana*, Kerr, 1792) distribution and northern range limits have been extensively studied (Guilday 1958) and opossum populations have been observed moving northward in recent decades (Brocke 1971; Guilday 1958; Kanda 2005). Originating from South America, the Virginia opossum was able to enter North America during the Great American Interchange (~2.8mya) when species migrated both north and south after the formation of the Isthmus of Panama (Hsu 1988). Today, the Virginia opossum is the only marsupial in North America, expanding from Central America to parts of Canada and along the west coast of the United States (Nigenda-Morales et al. 2018). As North America's only living marsupial, it raises the question as to why the Virginia opossum was the only species from the order Didelphimorphia to expand north of Mexico (Guilday 1958). With an ability to adjust to a large variety of climates and landscapes (Kanda 2005), the Virginia opossum is a good model species for studying the limits and drivers for species distribution expansion.

The Virginia opossum has great environmental and ecological importance. Being hunted by apex predators, opossums have become an important prey (McManus 1974). The opossums' widely varied diet also contributes to preventing the overflow of carrion and controlling insect populations that have the ability of spreading vector-borne diseases (McManus 1970). Historically, the hunting of Virginia opossums has been documented by Native Americans and arriving Europeans (Brocke 1971). Used as food and sold for their pelts, opossums contributed to the trade and consumption of early European settlers in North America. The contributions to both the environment and economy of opossums' past and current environments allows for prediction of how the species may influence new environments as their distribution continues to expand.

The Virginia opossum is a small, stout bodied marsupial that grows to the size of a house cat and adults weigh on average 2.8kg for males and 1.9kg for females (McManus 1974). The coat varies in color, typically a white to grey with speckled black. The ears, feet, and long thin tail are naked with an opposable digit on the hind feet which, along with the help of their prehensile tail, allows them to be semi arboreal and climb along branches. Small prey is preferred by opossums, however; vegetation and carrion is consumed (McManus 1974) and corphagy and cannibalism is observed during times of resource scarcity (Brocke 1971). Foraging and other activity happens at night; however, diurnal switches have been documented when temperatures are low. (Brocke 1971). The average litter size is around 6.8-8.9 joeys with up to three litters per year in ideal environments (McManus 1974). Young are altricial and continue to develop in the pouch attached to a nipple after birth (McManus 1974). Once weaned, joeys are carried on the mothers back and later leave the litter entirely. Adult opossums are usually solitary, becoming hostile around both conspecific and heterospecific individuals (McManus 1970). Hissing, growling, and playing dead are used during threatening encounters. Without strong defense mechanisms and escape tactics, the Virginia opossum is a vulnerable prey and rely heavily on shelter for protection. With a life expectancy of 1.33 years (McManus 1974) there is a high mortality rate in the first year of life due to predators or harsh weather conditions. Tree hallows, brush piles, fallen logs, and abandoned dens are used during the day to create an optimal microclimate and a hidden shelter to protect individuals (Brocke 1971). Virginia opossums have a low average body temperature of 35°C (McManus, 1974; Hsu, 1988) and basal metabolic rate (BMR) of 0.15 ml O_2/hr/g of body weight for a 3.5 kg individual (Brocke 1970). Recent studies have discovered much of the physiology of the Virginia opossum. Understanding life history traits is important in predicting how climate change will affect a species and where their population is capable of expanding.

Through fossil records and trends in range expansion, researchers have determined that the Virginia opossums' frequent range expansions are due to two factors: urbanization from growing human populations (Kanda 2005) and adaptations to colder temperatures (Nigenda-Morales et al. 2018; Pacifici et al., 2020). As the species has established populations further north than initially predicted, opossums have proven adaptability in order to establish populations in areas where they once could not (Kanda, 2005; Huey et. al., 2012). Opossums were able to move northward while human colonization was growing throughout America, taking advantage of fewer predators, of human food sources, and of increased shelter (Kanda 2005). Phenotypic plasticity and behavioral changes have allowed opossums to survive colder winters (*sensu* Huey et al. 2012). Comparisons of southern living Virginia opossums to those living in the north have shown various cold-living adaptations (Nigenda-Morales et al. 2018). This species is seen to follow Allen's, Bergmann's, and Gloger's rules where the northern individuals have decreased appendage size, increased average body weight, and decreased coat pigment respectively in order to reduce heat loss and camouflage for survival (Nigenda-Morales et al. 2018). Although primarily nocturnal most of the year, during the cold winter opossums have been observed foraging during the day while temperatures are warmest. The use of ground dens creating microclimates and having a wide diet variety assists the species in surviving through harsh winters (Brocke 1971). Opossum adaptability to both urbanization and colder temperatures gives insight on the species' success in their movement northward.

The Virginia opossum have adapted to increase chances of winter survival through phenotypic and behavior adaptation, however, they have physiological limitations that prevent the species from expanding northward indefinitely. Virginia opossums with denser undercoats in northern individuals (Nigenda-Morales et al. 2018) still have poor thermoregulatory and insulation ability (Brocke 1970; Hsu et al. 1988). With naked ears, feet, and tail, heat loss is rapid through the appendages (Nigenda-Morales et al. 2018). Lack of fur on the appendages is also prone to severe frostbite (Brocke 1971). Opossums are also tubular and long in shape creating a lot of surface area for heat loss. Virginia opossums have yet to show any signs of hibernation or torpor (Hsu et al. 1988). The species heavily relies on thermogenesis, vasoconstriction, piloerection, shivering, and behavioral avoidance during a harsh winter (McManus 1974). One-third of total winter energy for Virginia opossum is provided by catabolism of stored fat and body tissue (Brocke 1971). Opossums were observed in Michigan from December to March, in which female opossums were 38% lighter and males were 31% lighter than their starting weight before winter began which is a higher percentage loss compared to over-wintering mammals of similar sizes (Brocke 1971). Virginia opossums that were artificially exposed to winter temperatures but provided unlimited food supply still lost weight (Hsu et al. 1988). This is due to the increased energy cost of maintaining a constant body temperature in the cold. Virginia opossums' metabolism has been measured to increase from 0.15 ml O_2/hr/g of body weight/hr. for a 3.5 kg individual to 0.5 O_2/hr/g of body weight/hr. when temperature reaches below 0°C (Brocke 1970). An increase in energy expenditure can rapidly decrease fat stores so opossums usually remain confined to their dens when temperatures do not exceed 0°C to avoid unnecessary energy costs. Increased energy expenditure in winter months emphasizes a necessity to increase in weight and be able to forage before and during winter months When opossums are able to leave their dens, it is important to forage. Foraging is difficult in the winter due to snow cover (Walsh and Tucker 2018). Virginia opossums are unable to dig through snow and ice to find food if the snow cover is over 5cm (Kanda 2005). As major prey for many carnivores, most of the opossum population consists of juveniles that are naive to foraging and predator avoidance. Additionally, being small makes storing fat, increasing undercoat, and retaining heat even more difficult than adult opossums (McManus 1974). With a combination of small size, heat loss, increased energy expenditure, inability to forage, and low temperatures limiting activity, opossums have a difficult time surviving harsh winters and most individuals die of starvation. Virginia opossums are limited to their northern limits by two abiotic factors; snow cover and low temperatures in the winter month that lead to starvation (Kanda 2005; Blair 1936; Walsh and Tucker 2018).

For Virginia opossums to survive in environments where winter lasts over four months they need a certain amount of successful foraging days that provides the individual with enough energy to support them throughout the winter. Places, such as Maine, that have harsh winters have been experiencing the arrival of opossums in their southern regions due to warming winter temperatures from climate change. The Virginia opossum expansion entered New England around the 1900s and later the population reached into Southern Maine around the late 1990s, early 2000s (Nigenda-Morales et al.

2018). Individual opossums were seen as far north as places like Bangor, ME when taking advantage of warmer winters, however, stable populations have yet to be established north of Augusta, ME.

Maine, during the warmer months, provides an ideal environment for Virginia opossums. Maine's variety of farmlands, scattered water sources, increasing urbanization, species who create dens, and stable insect and amphibian populations all contribute to supporting Virginia opossum success. The cold, long winters and ample snow cover is what currently limits the species to the southern parts of the state. In this study, I will estimate the likelihood of Virginia opossums moving northward throughout the state of Maine. I will also estimate how urbanization will affect opossum population growth and establishment as well as how the species will contribute ecological importance to new areas in the state of Maine. I will test the prediction that the number of active days for the opossums is increasing as global temperatures continue to warm.

MATERIALS AND METHODS

Previous research has indicated that opossums require at least 50 days where temperatures reach over 0°C throughout a four-month winter for survival (Brocke 1971). Therefore, days where temperatures did not exceed 0°C were considered rest days for opossums and possible foraging days were days where the max temperature exceeded 0°C.

In order to evaluate changes in winter climate proximal to the study site, I extracted daily and mean temperatures from the PRISM dataset (Parameter-elevation Regressions on Independent Slopes Model , Daly et al., 1997; https://prism.oregonstate.edu/). PRISM models temperature data, compiles climate variables and stores them in order to recognize trends in climate. Maximum and mean temperatures modelled for Bangor, ME from December to March of the years 1981 to 2021 were downloaded from the PRISM dataset using the R package "prism" (Hart & Bell 2015). I used temperatures for Bangor due to the close proximity to the University of Maine.

Temperatures collected by a weather station are a good indication of ambient temperatures and datasets of these recordings can give insight on trends in the changing climate, ambient temperature does not fully capture what species experience in an environment. With this in mind, I recorded microclimate temperatures for the winter in the University of Maine's forest to determine if the 2020-2021 winter conditions could have supported a population of Virginia opossums. Temperature recording data-loggers (DS1922L Thermochron iButtons, Dallas Semiconductor, Dallas, TX, USA) contain sensors that are able to record information about an environment for long time periods after they are placed in the appropriate position. The data-loggers were first programmed to record temperatures in 45 minute intervals from 1 December 2020 until 31 March 2021. I created 12 microclimate temperature models by water sealing the data-loggers and placing them in a small water bottle covered in matte black tape and paint. I chose to use water bottles because they have very little insulative ability and I used matte paint and tape to limit sun reflection. I positioned the data-loggers so that they were not touching the sides of the water bottles in order to limit conduction between the sensor and the surface of the water bottle. Insulation, sun reflection, and conduction would alter the temperature collection. Four microclimate temperature models were placed at three different locations in the University of Maine's forest (Fig. 1); I secured two to the ground and tied two to branches on the tree at varying heights using metal wire (Fig. 2). I chose this study site due to the University Forest's characteristics that would support a Virginia opossum population, such as ample food sources, microhabitats, and limited number of large predators. Data collection was approved by the University Forest Office at the University of Maine. I collected the data-loggers at the end of March and was able to download the recorded temperature data using 1-Wire software. I used R programming software and Rstudio to compare daily maximum and mean temperatures.

Figure 1. Placement of temperature data loggers in the University Forest. Microclimate temperature models were placed in the University Forest in Orono, ME. Four models were placed at three different trees in a linear transect indicated by the red arrows.

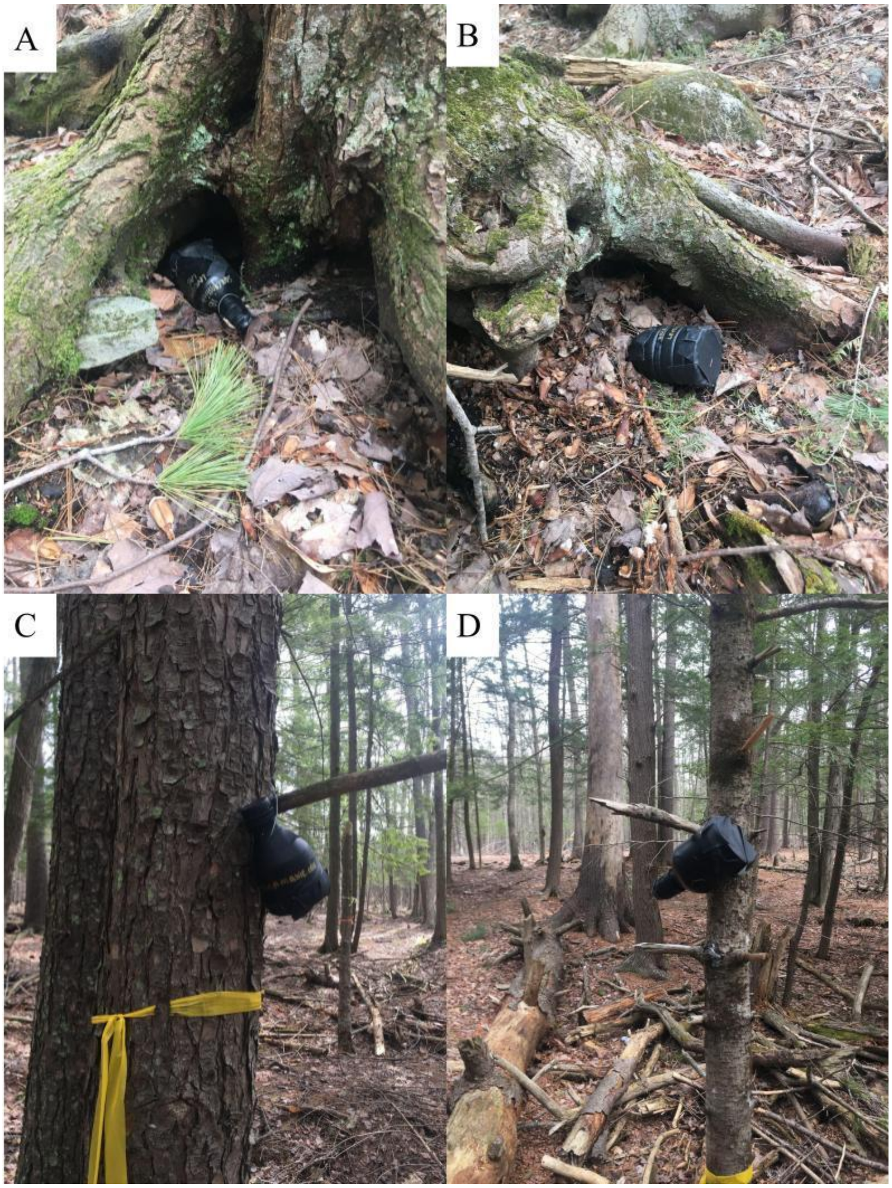

Figure 2. **Placement of temperature data loggers in tree locations.** Microclimate temperature models were placed at varying heights in each tree. Four models were placed near and in a tree at three locations. **(A, B)** Ground microclimate temperatures (T_{ground}) and **(C,D)** Tree microclimate temperatures (T_{tree}) were recorded.

RESULTS

Using yearly winter averages, I graphed average temperatures from 1981 to 2020 for Bangor (Fig. 3). In more recent years, winter averages tend to be higher than in later years. Peaks above 0°C are now much larger in the last 10 years when compared to previous years, this shows that mean winter temperatures are trending slowly upward.

I also used the PRISM temperature data to compare the count of possible active days for the Virginia opossum in Bangor across the last four decades (Fig 4). There is extreme variety in maximum daily temperatures throughout the winter. There is not one decade that had consistently more active days when compared to the other decades. Large variations among the number of active days between the four decades shows that there is no linear change of increasing number of active days. With rising average temperatures, I was expecting to see a trend in the rising number of active days for the Virginia opossum. The boxplot shows, however, that the number of active days for most years is above the minimum amount, 50 active days, required for winter survival. This supports why the climate in the area of Bangor could support small, infrequent populations of Virginia opossums in the past, but the more recent high variability of maximum ambient temperatures now precludes the growth of stable populations.

I collected the microclimate temperature models placed in the University Forest in Orono, ME this past winter (2020-2021) and I graphed a line graph showing data values taken in 45 minute intervals from 1 December 2020 to 31 March 2021 (Fig. 5). There was very little temperature difference between the model on the ground (T_{ground}) and the model that was up in a tree (T_{tree}). Based on the data from the microclimate temperature models, Virginia opossums likely would not have been able to survive the past winter in the University Forest. The number of active days from December to March was 42, which is less than the estimated 50 foraging days required for winter survival. Most of the days that were above freezing were in December and late March, demonstrating a long stretch of days where activity would not be possible in both January and February. Using temperatures collected every 45 minutes, there was a large frequency of temperatures below 0°C (Fig. 6). I then compared this to daily maximum temperature recordings throughout the winter to make the microclimate data comparable to the data obtained from PRISM (Fig. 7). When only daily maximum temperatures, such as those obtained from PRISM were considered, the data graph shows a right skew, and therefore overestimate the number of possible foraging days available for opossums.

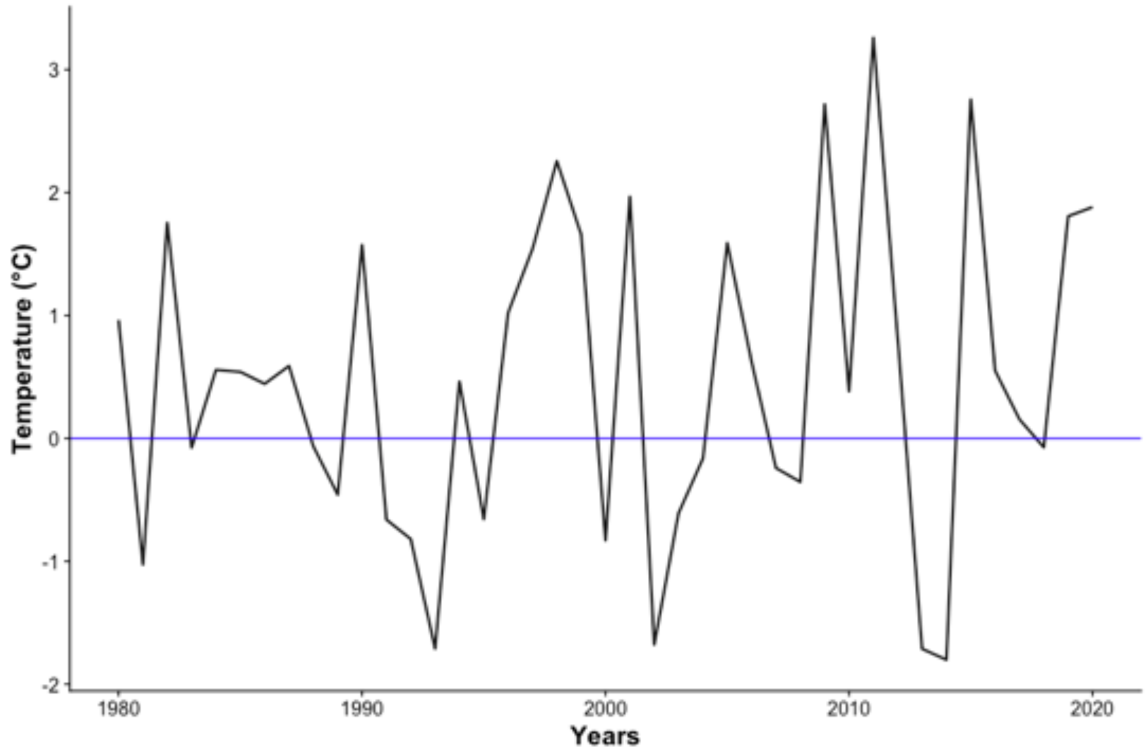

Figure 3. Mean winter temperatures are increasing in Bangor, ME. Winter average temperature anomaly for December- March (DJFM) from 1981-2021 shows a gradual incline in Bangor. The blue line represents the temperature limit for Virginia opossums. Winter temperatures are slowly increasing in Bangor based off temperature modelled by the PRISM climate group.

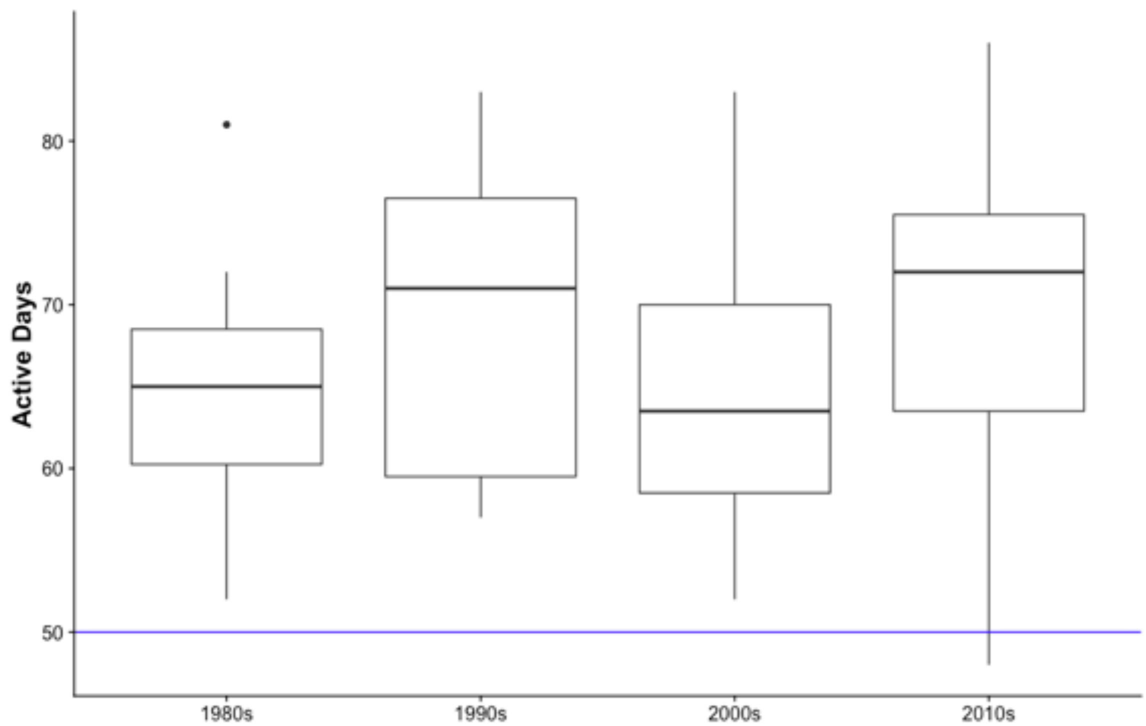

Figure 4. **Large variations in opossum active days in Bangor, ME**. Active days were graphed per decade in Bangor from 1981-2021 from data modelled by the PRISM climate group using maximum daily temperatures. Black horizontal lines represent the median value for each decade. Active days are days where the temperature reached above 0°C. For most winters, active days were above the minimum required 50 active days, represented by the blue line. The graph represents very variable means and large ranges between lower and upper extremes, showing a large variation in active days among the decades, revealing no real trend.

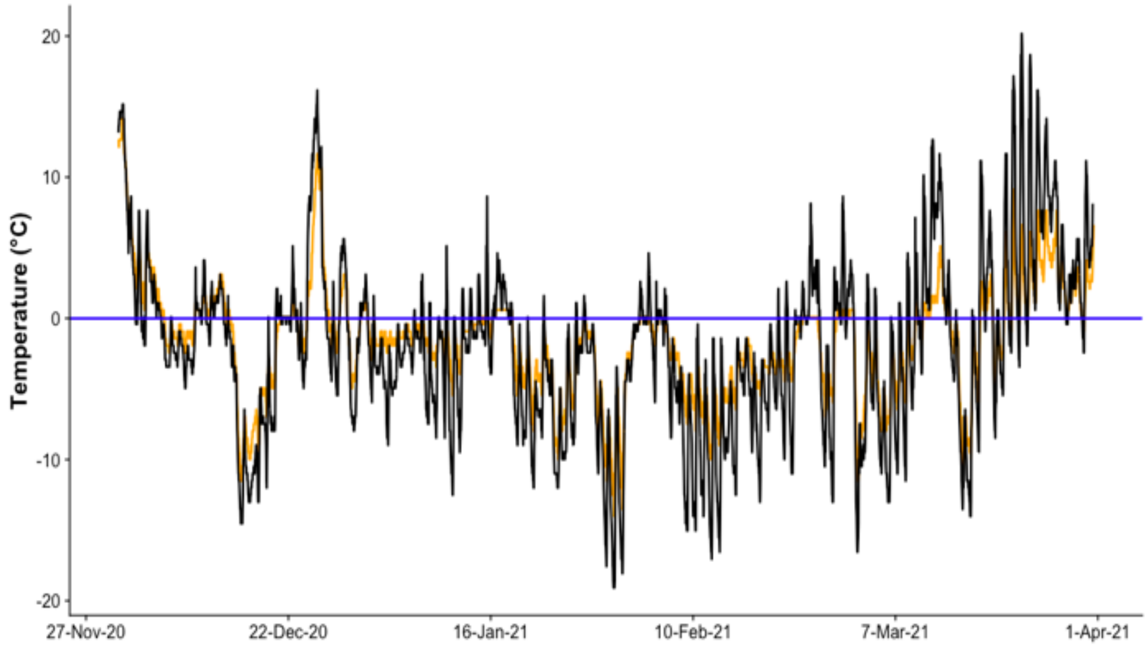

Figure 5. **Winter temperatures collected from data loggers in Orono, ME.** Data collected from microclimate temperature models that were placed in the University Forest in Orono from 1 December 2020 to 31 March 2021. Temperature was recorded in 45 minute intervals. Ground (T_{ground} = Orange and tree (T_{tree} = Black) microclimate temperatures were recorded, showing very little variation between the two. Data points above 0°C (blue line) are considered temperatures Virginia opossum can be active outside their dens. Most active days were in December and late March.

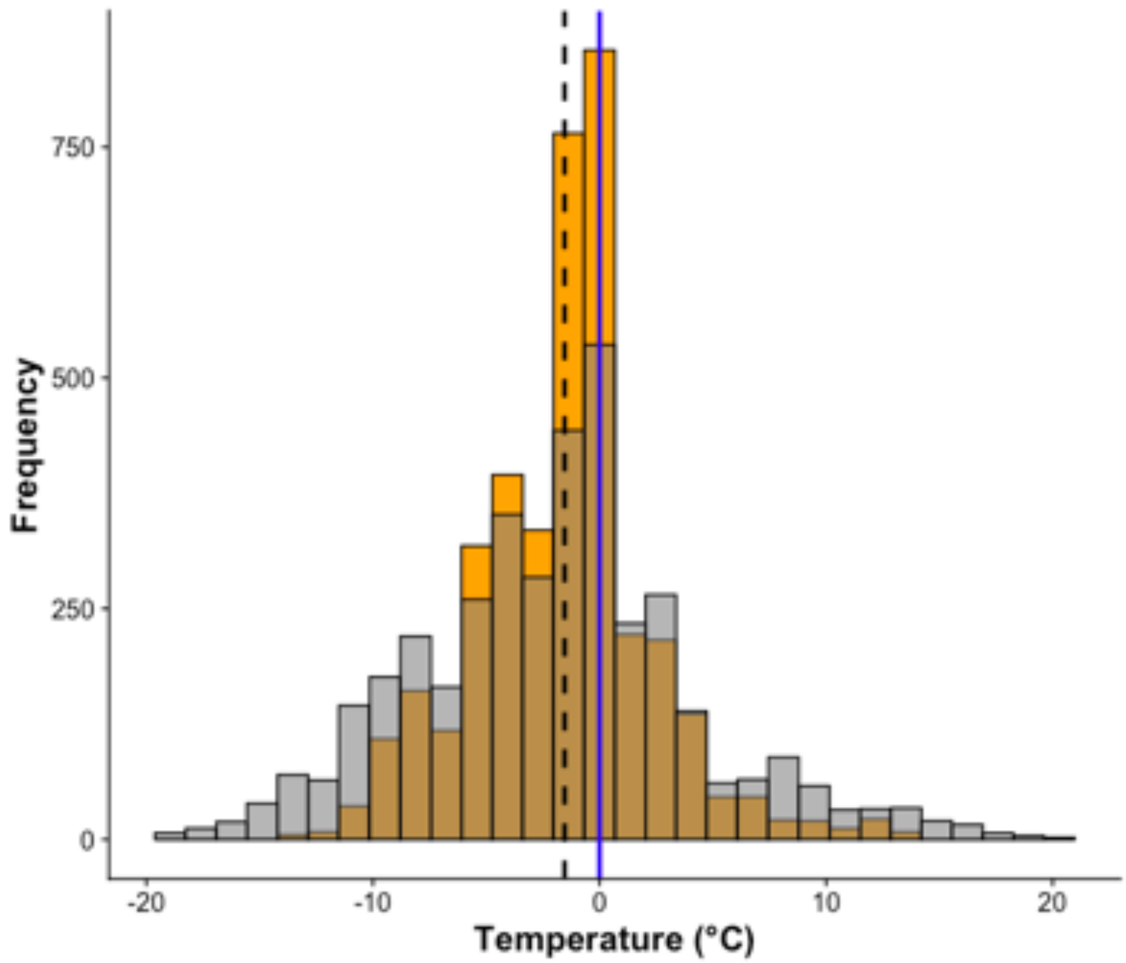

Figure 6. **Frequency of daily interval winter temperatures in Orono, ME**. Frequency of temperatures recorded by ground (T_{ground} = Orange) and tree (T_{tree} = Grey) microclimate temperature models that were placed in the University Forest in Orono over the winter (2020-2021). Data to the left of 0°C (blue line) indicated temperature that would restrict Virginia opossums to their dens and to the right would be temperatures that would allow for activity. The graph shows a larger amount of recorded temperatures that would not allow for opossums to leave their dens. The mean (black dashed line) indicated an average of temperatures lower than 0°C throughout the winter in Orono. From 1 December 2020 to 31 March 2021 there were 42 days where temperatures were above 0°C, which is below the minimum of 50 days required for winter survival.

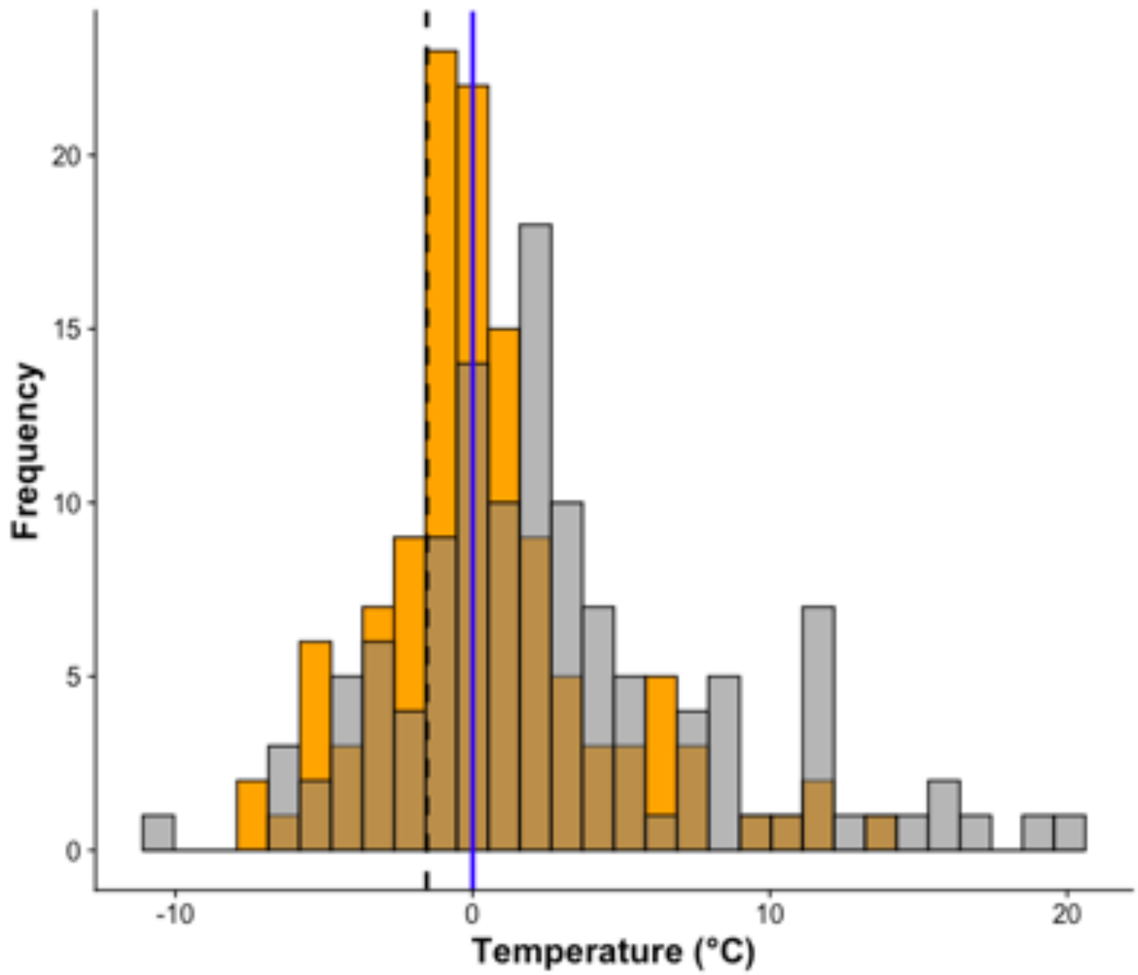

Figure 7. Frequency of daily mean winter temperatures in Orono, ME. Frequency of maximum temperatures recorded by ground (T_{ground} = Orange) and tree (T_{tree} = Grey) microclimate temperature models that were placed in the University Forest in Orono over the winter (2020-2021). Data to the left of 0°C (blue line) indicated temperature that would restrict Virginia opossums to their dens and to the right would be temperatures that would allow for activity. Data presented only includes the maximum temperature for each day of the winter.

DISCUSSION

The data from PRISM dataset indicated that mean winter temperatures from 1981 to 2020 has been slightly increasing in Bangor, ME (Fig 3). Most winters throughout the years had over 50 days between December and March where maximum daily temperatures reached higher than 0°C. However, without snow cover taken into account, it is difficult to accurately say that Bangor, ME can currently sustain a population of Virginia opossums. Even on days where temperature does not limit opossum activity, snow cover can cause forage failure and reduce the number of successful foraging days needed for winter survival (Walsh and Tucker 2018). The data comparing the amount of active days between the decades showed no obvious trend and that the amount of active days is still very variable (Fig 4). Variability in weather conditions makes the growth of long term residency difficult for new species (Parmesan et al. 2000). It is possible that if I was able to collect climate data from further back in history there could have been a visible trend, however, due to the short 40 years that I was available from the PRISM dataset, it is difficult to make any assumptions about trends in number of days above 0°C in a winter season. It is also possible that Bangor's winter temperatures permits for opossum establishment and that opossums have not yet expanded into Bangor.

Although other areas of Maine have had changes in winter climate that has become more favorable for opossum populations, this study suggests that central Maine, specifically the city of Orono, is still too cold to support a stable population of opossums for continuous years. Data collected from placing microclimate temperature models in the University of Forest in Orono only measured 42 days where temperatures reached above

0°C. With less than the minimum 50 active days required, opossums could not have survived a winter in the University Forest. It is highly likely that the actual number of successful foraging days would be much lower than what was predicted by measuring microclimate temperature due to amble snow cover that persists in the forest. When frequency of maximum daily temperatures was graphed, a larger portion of data indicated active day temperatures when compared to frequency of temperatures recorded every 45 minutes. The use of maximum temperatures only created a heavy skew. This is similar to the data gathered from the PRISM dataset. As only maximum temperatures for each year of the winter was used, graphs of this data might be misrepresented and the amount of actual foraging days would be overestimated. To avoid this, continuous temperature taken in intervals should be used to accurately describe winter temperatures.

Snow fall and coverage prevents opossums from foraging by not being able to dig through thick snow (Kanda 2005; Walsh and Tucker 2018). With no signs of hibernation and the limited food sources in opossum ground dens, feeding outside the den regularly throughout the winter months is vital for survival (Brocke 1971; Kanda 2005). Although snow cover was not able to be modeled in this study, it is predicted that with the rising temperatures comes a decrease in snowfall and snow cover and an increase in bare patches of melted snow (Kearney 2020). Virginia opossums have been seen active while snow is on the ground as long as the temperature allows for the leaving of dens. Opossums are seen foraging on bare patches where snow has melted, under decks in suburban areas where snow could not accumulate, and around tree roots where snow build up is less likely (Brocke 1971). Because of these observations, it is difficult to predict when snow would prevent foraging for opossums, due to the randomness of bare patches and snow clearing by humans. It is also very likely that opossums living around humans, where snow is cleared often, would find foraging spots even when snow cover is thick in surrounding areas. With this being said, snow cover has been seen to limit the advancement of species northward (Kanda 2005; Walsh and Tucker 2018). With small range sizes and lack of migration evidence, areas where snow persists consistently throughout a winter, such as forests and large farm fields, would prevent opossum survival by making food sources unobtainable. The University of Forest, where snow is not cleared and snow cover persists, it is likely that the number of foraging days would be even lower if snow cover was taken into account. For future research, a study done where both temperature and snow cover is modelled, taking into account bare patches and snow clearing, would allow for a more accurate prediction of the likelihood of opossum survival in new environments.

Virginia opossums have expanded their range past previously predicted physiological limits (Kanda 2005). This causes doubts that abiotic factors alone contribute to opossums' inability to indefinitely expand northward. Starting weight and age of opossums in autumn are two biotic factors that contribute largely to the species' northern distributional limit (Kanda, 2005; Hsu, 1988; Nigenda-Morales et al. 2018). For both hibernators and non-hibernators, fat stores contribute by providing energy when food is scarce and increasing insulations to prevent heat loss in low temperatures (Brocke 1971). This causes the accumulation of fat stores during autumn to be a top priority for overwintering species. Kanda (2005) conducted a study in which a model was used to predict opossum survival throughout the winter based on autumn weight. This study pointed out that the majority of opossum populations are juvenile due to the species being a common prey and that to sustain a population of opossums in an area 67% of juveniles must survive the winter in order to reproduce in the spring and continue a stable population. As juveniles, the pressure of harsh winter elements is increasingly dangerous due to their small size not allowing for ample fat stores and undercoat build up. Knowing this, the mass of individuals obtained at the start of the winter is able to determine probability of survival and when creating models of species potential movement into new environments, size of the population majority, not just adult weights, should be taken into account. As juveniles account for a majority of opossum populations in their current environment, I chose to use a 50-day foraging minimum for winter survival based on Brocke's 1971 estimates. It is possible that adults could survive winters with fewer foraging days, however, juveniles would most likely die of starvation, leading to population instability and eventual decline. There have been few sightings of opossums being active when temperatures were below -4°C (Hsu et al. 1988), however, these opossums were large adults that do not represent the majority of the opossum population, thus the president for foraging ability was set at 0°C to account for juveniles that make up most of the population at any given time.

Virginia opossums' exposure to harsh winter elements is known to cause starvation and death, however, opossums are seen in environments that experience four month winters, like most of the northern east coast of the United States, such as Michigan (Brocke 1971) and Massachusetts (Kanda 2005). Microclimates likely contribute to opossum survival throughout winter by providing the minimal coverage needed to protect from predators and limit their exposure to low temperatures. As excellent climbers, opossums are able to utilize hollow trees and fallen brush piles for shelter. During the winter months, most opossums are seen to switch to ground dens that are warmer (McManus 1974). The shelters are surrounded and create a microclimate for the animal to be able to avoid harsh weather conditions. Microclimates are areas where the climate differs from the surrounding macro habitat (Brocke 1971). Insulated under snow cover, ground dens are warmer than the ambient temperature. Virginia opossums, along with other woodland creatures, overwinter insects, and valuable soil microbes take advantage of microclimates to buffer climate and reduce mortality from harsh weather events (Scheffers et al. 2014). Without continuously being exposed to the dropping temperatures throughout the winter months, Virginia opossums are able to reduce energy expenditure.

When not foraging for survival, opossums stay in dens to limit the exposure to the low ambient temperatures (Brocke 1971; Hsu 1988). In accordance to this assumption, I used microclimate temperature models in this study to determine when opossums would be able to be active outside their dens and when temperatures restricted them to remain inside their microclimates. It was assumed that if temperatures were below 0°C, opossums are unable to forage as opossums remain in their dens to avoid the high energy cost of being exposed to freezing temperatures. Data collected from these microclimate models indicated that microclimates in the University Forest could not support opossums through the last winter (2020-2021). As climate change also contributes to the duration and frequency of extreme weather events (Gao et al. 2012), these dens are important for opossum survival as climate change continues to show its effects. Climate change put species at risk due the rapid rate of change not allowing for quick enough adaptations (Mitchell et al. 2018; Huey et. al. 2012; Parmesan et al. 2000). Ability to find microclimates to guard from extreme conditions will determine the effects of climate change on a species. Inability to find shelter could be an issue for the Virginia opossum because they do not have the capability to create ground dens and tree hollows themselves. Opossums find these abandoned habitats that were once created by other species. Burrowing terrestrial animals such as skunks, woodchucks, and badgers are vital species to animals, such as the Virginia opossum, in creating necessary shelter and microclimates (Brocke 1971). Reliance on other species to create dens suggests that opossums must live among burrowing species in order for survival. When predicting the likelihood of opossum survival into new environments, the presence of burrows and burrowing animals should be considered. It is likely that opossums would survive in areas where woodchucks (*Marmota monax*) have a stable population or in areas where woodchucks were established due to woodchucks excelling at constructing large burrows (Brocke 1971). The University of Maine Forest contains many hollow trees that red squirrels currently take advantage of and fallen trees and foliage that would create microclimates. Search for more advanced dens in the University Forest would have to be done to accurately describe the Virginia opossum's potential success on campus.

Human colonization and the success of Virginia opossums expanding northwards has seemed to coincide throughout history. Documented by pioneers, fossil remains, and more recent observations, the simultaneous progression is evident (Brocke 1971; Walsh and Tucker 2018). Therefore, it is likely that increasing human population and settlement has heavily contributed to opossum range movements and establishments of populations in a wide variety of environments. It is thought that the clearing of large forests, the increase in crop production, and the decrease in predation in urban areas contributes to Virginia opossum success near humans (Wait et al. 2020; Walsh and Tucker 2018;

Troyer et al. 2014). Human establishment in new areas has shown to decrease the size of animals on average due to land use and the destruction of major habitats. Most smaller woodland mammals are able to benefit from human populations. Increase in crop production, roadkill, and garbage consumption, animals are able to take advantage of consistent food sources. The establishment of homes and other infrastructure also provides increased shelter spots such as underneath decks and in crawl spaces of homes. Among the increase of small animals, human settlement contributes to the recruitment of burrowing animals. As mentioned, burrowing animals are crucial for opossums to seek shelter. Urban areas have also known to have a higher air temperature on average when compared to surrounding rural areas. A temperature difference in cities is due to a climatic phenomenon known as the urban heat island effect. Heat islands form through high energy consumptions, the building of infrastructures, and pollution (Shahmohamadi. et al. 2011). As Virginia opossums and other small animals struggle to survive winter months due to low temperatures, settlement around urban areas is more likely due to the slightly warmer air temperatures. Providing ample food supply, contributing shelter spots, pushing out a majority of large predators, and increasing ambient temperature, human settlement helps support Virginia opossum populations and produce more favorable conditions for winter survival (Wait et al. 2020). With this evidence of urban areas supporting opossums in their current distributions, I estimate that urbanization in the state of Maine will positively affect Virginia opossum population establishment and growth as the species continues to expand throughout the state.

The Virginia opossums' ecological importance plays a vital role in understanding the effects the species will have when expanding into new regions. Species entering new environments have the potential greatly alter the community by competition, predation, and introduction of vector-borne disease (Walsh and Tucker 2018). As Central Maine is predicted to become increasingly favorable in order to support opossum populations, their relationship with their environment is necessary to understand in preparation for their arrival (Troyer et al., 2014). It is well known that opossums are a valuable prey (McManus, 1974) and it is likely that, with Maine's abundance of predatory birds and large mammals, the addition of a species to the prey diversity would positively affect Maine's valued predators. Virginia opossums also eat insects. Maine is continuing to see a climb in Lyme Disease cases due to the rise in black-legged tick populations (Elias et al. 2020). A study where done examining mammals infested with ticks, showed that Virginia opossums consume 95% of ticks that try to parasitize them (Keesing et al. 2009). Opossum addition into new areas of Maine have the possibility of slowing the rise in populations, and thus the spread of Lyme Disease, by preventing ticks from continuing their lifecycle. Virginia opossums can be vectors of zoonotic diseases, most commonly leptospirosis, that have the ability to pass to humans and pets (Keesing et al. 2009). Leptospirosis is a bacterial infection that spreads through urine and feces. Vaccines are available to protect dogs and cases in humans are extremely rare, but caution around any wildlife is always strongly suggested. The likelihood of opossums being infected with rabies is extremely rare. Laboratory studies showed that infection of adult opossum was difficult, but juveniles were more susceptible (Keesing et al., 2009). In the wild, however, juveniles rarely survive predatory attacks and thus the transmission of rabies from opossums is negligible. It is also possible that, due to the urbanization favoring opossum populations, humans might encounter opossums more often and view the species as a pest. It is important to keep garbage locked away and opening into homes and buildings closed as they have the possibility of attracting the species and many other woodland creatures (Kanda 2005). Most environmental impacts are thought to positively impact the state of Maine and with little evidence of disease transmission, the Maine public should not fear the arrival of Virginia opossum in new areas of Maine as risk to public health is slim.

Long-term climate data is important to monitor environmental changes. Datasets have the ability to reveal short and long-term trends. Recognizing patterns in climate data can allow us to make future predictions, prepare for the effects of climate change, and take measures in reducing the forerunners of climate change. Predicting how climate change may affect a species can also be beneficial (Parmesan et al. 2000). Understanding an environments' potential loss or gain of a species allows time for human and land preparation and the establishment of necessary conservation plans (Mitchell et al. 2018). It is important to recognize that although Virginia opossums will benefit from the growing human population and the warming temperatures from climate change, many more species will see a decline in population size due to both factors (Pacifici et al. 2020). It is through the recognition of climate trends and its effects that will draw attention to the importance of climate research and preventative planning.

CONCLUSION

As North America's only living marsupial, the Virginia opossum is an interesting species to study versatility and adaptations to various environments and to the changing climate. Movement of Virginia opossum northward has been well documented and is thought to be due to two ongoing events: colonization and climate change. Opossums' northern limit is restricted by two abiotic factors: low temperature and snow cover which prevent foraging and lead to starvation in the winter. Maine's climate is becoming increasingly favorable for opossum success and opossums will most likely continue to expand northward throughout the years as winter temperatures become less harsh. Both the starting autumn weight of individuals and the quality of microhabitats factor into winter survival. Human populations produce more favorable conditions for opossum population success and are predicted to positively impact opossum populations in the state of Maine. As excellent prey and insectivores, opossums have the potential of positively impacting new environments throughout the state, however, issues of being pest around homes and carrying disease could lead to need of control. Climate datasets and models help find trends in climate change throughout the years and predicting species loss or gain aids in conservation efforts and necessary preparation of environmental impacts. Although the Virginia opossums' range distribution is predicted to continue expanding in the face of climate change, many species will suffer from the effects of warming temperatures that will lead to decline and extinction.

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AUTHOR'S BIOGRAPHY

Sara R. Griffin majored in Zoology and during her time at the University of Maine became a member of Dr. Levesque's lab, was hired as a chemistry Maine Learning Assistant, and took a variety of animal focused classes. During the summer of 2018, Sara interned at a Wildlife Rehabilitation Refuge where she was exposed to wildlife care of woodland creatures. In the summer of 2019, Sara was hired as a field technician to help determine how deforestation affects population density and abundance of small mammals in some forests in Oregon and Washington. With exposure to opossums during her rehabilitation work and working to understand the effects of human land manipulation on wildlife, Sara was eager to discuss how climate change and urbanization was affecting the Virginia opossum species in her honors thesis. Sara values the University of Maine and all the experiences her time here has given her. With a new love for the state of Maine, Sara was excited to research a new species expanding throughout the state and how it may affect Maine's environment and people. She currently volunteers at a covid-19 vaccination center and her love of all living things inspires her to continue volunteer work that will help people and animals in the future. After graduation, Sara hopes to fulfill her childhood dream of attending veterinarian school.