ABSTRACT

Title of Thesis: SPATIAL ANALYSIS OF WHITE-TAILED DEER CAPTURE METHODS AND MOVEMENTS IN SUBURBAN MARYLAND

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Regions of the United States continue to experience an increase in zoonotic diseases. White-tailed deer support tick populations and implicated the emergence of several tick-borne diseases. Urbanization has elicited a dramatic increase in white-tailed deer populations. Consequently, the rise in deer numbers close to suburban areas has placed the public at increased risk of contracting disease. This study is part of an USDA-supported tick control project in Howard County, Maryland. The objectives were to 1) evaluate capture methods and provide recommendations for suburban trapping programs; and 2) evaluate spatial and temporal movement patterns and resulting impacts on risk of exposure to ticks. We found trapping deer in urbanized parks, during cold and snowy weather likely increased success. Different patterns in movement and space use of residential land can have important implications for humans' risk of exposure to disease, with female deer posing higher risk than males especially during winter months.

SPATIAL ANALYSIS OF WHITE-TAILED DEER CAPTURE METHODS AND MOVEMENTS IN SUBURBAN MARYLAND

by

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Chapter 1: Introduction

White-tailed deer (*Odocoileus virginianus*) populations have recovered from historic lows in the early 1900's and are now a common occurrence in a wide range of habitats (Adams et al., 2009). Their adaptable habits and lack of predators have led to dramatic population increases and high densities, especially in suburban areas (Etter et al., 2002; McAninch, 1995). Urbanization and habitat fragmentation offer increased availability of edge habitat, ornamental plantings, and refuge from hunting and predation (Brownstein et al., 2005; Kilpatrick et al., 2017; Walter et al., 2018). Suburban developments in a network of public parks, woodlots, and agricultural lands have created a patchwork of high-quality deer habitat (Storm et al., 2007b; Walter et al., 2018). Urban and suburban habitat patches are connected via riparian buffers, road rights-of-way or verges, and utility corridors providing deer accessible routes to needed resources (Grund et al., 2002). Consequently, the rise in deer numbers close to suburban areas has increased the perceived risk of human-deer conflict such as deer-auto collisions, agricultural damage, and over browsing (Urbanek et al., 2011). Additionally, exposure to zoonotic disease is a growing concern.

Lyme disease is the most commonly reported vector-borne disease in the United States (Center for Disease Control and Prevention (CDC), 2017; Donohoe et al., 2015) and has increased in Maryland over the past two decades (Maryland Department of Health (MDH), 2019). Moreover, as the documented number of cases are an underestimate, the problem is likely worse than acknowledged (CDC, 2013). In Maryland, the transmission of tick-borne pathogens to humans is attributed to three species of ticks, namely the blacklegged tick (*Ixodes scapularis*), the lone star tick (*Amblyomma americanum),* and the

American dog tick (*Dermacentor variabilis)*. Blacklegged ticks and lone star ticks are considered the primary reservoir for Lyme disease and other pathogens, and are regularly found on white-tailed deer (Bennett, 1995; Wood & Lafferty, 2013).

In the 1990's deer research started to focus on understanding the role deer played in supporting or spreading of zoonotic diseases. Yet, we are still trying to understand the relationship between the environment and disease vectors to quantify disease transmission risk and identify effective monitoring and control methods (Brownstein et al., 2003). Past studies have agreed that spatial and temporal dynamics of both parasite and host play a large role in the transmission and persistence of tick-borne disease in the environment (Donahue et al., 1987; Gratz, 1999; Gray et al., 1992; Levi et al., 2012; Piesman, 1989; Turney et al., 2014), leading to elevated risk of Lyme disease in areas with suitable tick habitat, presence of infection, and high host densities (Donohoe et al., 2015). Moreover, the distribution and abundance of ticks along with the associated transmissions are linked to tick host densities (Brownstein et al., 2003, 2005; Gray et al., 1992; Means & White, 1997; Pepin et al., 2012), with white-tailed deer as a keystone host for adult ticks (Wilson et al., 1990). As such, deer significantly contribute to the maintenance of tick populations and are implicated in the emergence of several tick-borne diseases (Brownstein et al., 2005; Gray et al., 1992; Levi et al., 2012; Wilson et al., 1990). In addition to the increase in host numbers, the increase in zoonotic disease in suburban areas may also be driven by greater habitat fragmentation (Brownstein et al., 2005; Childs & Paddock, 2003; Gratz, 1999; Kilpatrick et al., 2017; Wood & Lafferty, 2013). In our system, this may be further facilitated by the large ranges of deer enabling individual ticks to disperse further and colonize new habitat fragments (Brei et al., 2009;

Levi et al., 2012; Ostfeld et al., 2006; Roome et al., 2017). As such, uncovering patterns in deer use of suburban neighborhoods will have important implications for managing exposure to ticks and tick-borne disease.

Effective disease management will require an integrated approach of many management tools to control zoonotic diseases and other pathogens (Wobeser, 2002). Though most of the tick life cycle is spent off the host ticks must seek a host to complete each life stage. Thus, a host-targeted approach may be the best management tool to stop disease transmission. Solutions entail a combination of monitoring and surveillance of target host populations as well as intervention under certain circumstances (Wobeser, 2002). Studies have shown contrasting evidence for the recommended methods to reduce vector-based zoonotic disease risk to humans. Past research has involved live capture of white-tailed deer for disease monitoring or administering baits for vaccinations (Fischer et al., 2016; Miller et al., 2003; Turner et al., 2013; Wobeser, 2002), but many campaigns have been limited in their success or financial viability (Wobeser, 2002). Wilson et al. (1990) and Deblinger et al. (1993) both suggest that reducing deer densities will reduce human health risk of disease. Yet, many others document a nonlinear relationship between deer abundance or removal and rate of tick infection (Gray et al., 1992; Kugeler et al., 2016; Roome et al., 2017). Mysterud et al. (2016) documented the complex relationship suggesting Lyme disease incidence is related to increased densities of deer but controlling deer densities would have limited effect on reducing disease incidence due to diminishing returns at low densities. Wood and Lafferty (2013) suggested that reducing risk may be best applied when disease transmission is most sensitive or at a bottleneck, such as transmission from vector to host.

Objectives: The rising overlap between human and deer populations elicits the need for further research and management. The research presented here is part of a larger integrated tick management (ITM) project in Howard County, Maryland. The USDA-ARS Areawide Tick Control Project's main objective was to evaluate a combination of integrated tick control treatments on the interface of public and private land to reduce risk of tick-borne disease in local communities. A major component of the project required evaluating deer capture methods and movement before and after the implementation of host-targeted treatments.

Objective 1. Evaluate capture methods

Literature on capturing white-tailed deer specifically in suburban areas is limited, thus providing an analysis of capture methods would aid managers in planning future management activities. Here I determined if there was a difference in capture success among trap sites and evaluated the influence of land cover characteristics and weather on capture success, to allow for more targeted approaches. Additionally, I provided a supply list and recommendations to improve suburban deer trapping protocols.

Objective 2: Evaluate spatial and temporal movement patterns

Quantifying spatial and temporal dynamics of deer habitat use, home ranges, and movements are critical to understanding of how deer use the suburban landscape, and thus the spread of both their parasites and associated disease. To address some of these dynamics I created home range estimates using autocorrelated kernel density estimators which are compared among sex and season. Additionally, I compared movement rates across sex, time of day, and location. Lastly, I quantified the use of residential land and private property to understand potential control options in this system. Overall, my goal was to shed light on how deer move through this complex suburban landscape and the potential impacts on disease transmission to humans.

STUDY AREA

My research examined the GPS locations of deer captured from five county parks located in Howard County, Maryland (Fig. 1). Howard County is situated approximately 29 km south of Baltimore and 43 km north of Washington D.C. Howard County has a human population of approximately 325,690 people and is 650 km^2 with a population density of 501 people/km^2, which is twice the average for Maryland (U.S. Census Bureau 2019). Median household income within Howard County was $121,618 which is nearly double the U.S. median (U.S. Census Bureau 2019). All five study sites were within the metropolitan zone of Howard County, which delineates boundaries for public water and sewer services and is characterized by heightened urban development and population density (Fig. 2). The metropolitan zone had 9.64 persons/ha, versus the more rural western portion of the county with 1.24 persons/ha. On average, annual rainfall was 1.09 m and annual snowfall was 0.58 m (Kraft, 2008). In winter, the average temperature was 0.78°C and the average daily minimum temperature was -4.9°C degrees (Kraft, 2008). The lowest temperature on record, which occurred on 22 January 1984, was -27.8°C. In summer, the average temperature was 22.9°C and the average daily maximum temperature was 29.6°C. (Kraft, 2008). Soil across the state is predominately sassafras sandy loam and high proportions of clay (Kraft, 2008). Soils in the eastern portion of the county have been highly disturbed due to development and urban sprawl (Kraft, 2008, Maryland Department of Natural Resources (MDNR), 2016). Many of the soils in the county are well suited to intensive agricultural production (Kraft, 2008). Corn and soybeans were the primary crops grown during the study period (USDA NASS, 2017). The Piedmont Plateau region of Maryland is predominantly characterized by oak-hickory (*Quercus spp*. – *Carya spp*.) and oak-pine (*Quercus spp*. – *Pinus spp*.) forests (MDNR, 2016).

Cedar Lane Park is a 37.6 ha area with maintained paved trails, playgrounds, pavilions, and athletic fields. This park contains a small mature forest of oak (*Quercus spp.*), hickory (*Carya spp.*), tulip poplar (*Liriodendron tulipifera*), and American Beech (*Fagus grandifolia*). The understory was dominated by spicebush (*Lindera benzoin*) and intermittent patches of *Rubus spp*. There was limited open space created from a gas pipeline. Middle Patuxent Environmental Area (MPEA) is a 414.8 ha park with 8.85 km unpaved trail system at the southern portion of the property. Most of the property is mature oak, hickory forest with patches of managed early successional habitat of native warm season grass meadows. Autumn olive (*Elaeagnus umbellate*) was abundant in the understory. The Middle Patuxent River runs the length of the MPEA. The Wincopin Trail System had 5.5 km of trails within its 31.6 ha of forested oak, maple (*Acer spp.*), and American beech. American holly (*Ilex opaca*) was found in the understory along with Japanese stiltgrass (*Microstegium vimineum*) and Japanese honeysuckle (*Lonicera japonica*). It is bordered by the Little Patuxent and Middle Patuxent Rivers. Rockburn Branch Park is a 167.9 ha semi-wooded park with 14.5 km of paved and unpaved pathways. Forest composition is predominantly oak, American beech, hickory, tulip poplar with patches of eastern red cedar (*Juniperus virginiana*). Numerous invasive species were present in the understory including autumn olive, multiflora rose (*Rosa* *multiflora*), and Japanese barberry (*Berberis thundbergii*). This park included numerous athletic fields and courts, historic buildings, and a disc golf course. The Blandair Regional Park was divided into two parcels by a 4-lane divided highway. Trapping occurred on the north parcel which is approximately 60.7 ha of maintained grassy fields, unpaved paths, and wooded habitat consisting of black walnut (*Juglans nigra*), black cherry (*Prunus serotina*), and maple. Autumn olive dominated the understory but *Rubus spp*. and Japanese stiltgrass were also abundant. A historic farmhouse and surrounding outbuildings/barns were maintained on the property. All park properties were bordered directly by suburban neighborhoods and commercial buildings.

Deer density was estimated within various park properties by county police and county Recreation and Parks personnel using Forward Looking Infrared (FLIR) helicopter surveys. Deer densities within the parks ranged widely from 12.5-174 deer/km^2 (Table 1). Deer density was not calculated for Cedar Lane Park in 2017 or 2018. Deer density at the MPEA was estimated at 41 and 21 deer/km^2 in 2017 and 2018. Deer density in the Wincopin trail system was not evaluated. However, the neighboring Savage Park (28 ha) had an estimated deer density of 12.5 deer/km^2. Deer density at Rockburn Branch Park was calculated at 17.0 and 61.9 deer/km^2 in 2017 and 2018, respectively. Total deer numbers for Blandair Regional Park were estimated at 174 deer/km^2 in 2018.

A majority of residents in the county believe the deer populations needed to be managed or reduced (Norris, 2008). The Howard County Recreation and Parks Department implement deer population control at various parks via sharpshooting or managed hunts. Sharpshooting is conducted at night over bait piles by licensed marksmen. Managed hunts are restricted to shotgun and archery hunting by registered public participants. Middle Patuxent Environmental Area, Blandair Regional Park (north), and Wincopin Trails System have had annual managed hunts since 1998, 2003, and 2014 respectively. Deer in Savage Park (directly adjacent to Wincopin Trails area), Rockburn Branch Park, and Blandair Regional park (north) have been managed by sharpshooting since 2007. Managed hunts are not conducted in Cedar Lane Park (Table 1).

FIELD METHODS

Trapping Methods

The 2017 trapping season occurred February–April and the 2018 season occurred January–April. In 2017 Cedar Lane Park, Wincopin Trail System and MPEA were trapped. Rockburn Branch Park and Blandair Regional Park were added to the trapping schedule in the 2018 season. Deer were captured using drop nets (15.2m x 15.2m) and box traps (0.9m Width x 1.22m Height x 1.83m Length) (Wildlife Capture Services, Flagstaff, AZ) baited with whole kernel corn and apples. Exact drop net placement within each site was selected to reduce interference with human recreational activity while maintaining ease of vehicle access. An area large enough for the net was cleared of large debris and special care was taken to remove glass, metal litter, and rocks. After pre-baiting for three days, the net was erected and monitored with a Moultrie® M-888 camera trap (Moultrie Feeders, Birmingham, AL) to determine group size and frequency of visits from deer. Once a net had deer visiting daily, a hunting blind was erected > 25 m from the net. During each trapping event technicians would wait in the hunting blind and drop the net via remote control once a deer was positioned under the net. In addition to drop netting, four box traps were placed in areas of high deer activity but also hidden from human view to reduce interference. After box traps were placed, the area inside and directly outside the entrance were baited. In addition to Moultrie® camera traps, we used SPYPOINT® Link-3G (GG Telecom, Indianola, IA) cellular cameras to monitor box trap activity allowing for immediate alerts when an animal was captured. Trap doors were tied open for approximately 2 weeks until deer became familiar with the bait and entered the trap daily. We modified our box trap trigger wires to stand at least 30 cm above the ground to avoid false triggers from non-target animals. Box traps were set in the evening and checked once a day at dawn. Box traps were not permitted to be set for capture while the parks were open due to concerns of public interference even though camera trap data showed deer activity at box traps throughout the day.

When an animal was identified under a drop net, the field crew activated the net, physically restrained the animals, and anaesthetized animals by hand syringe in the gluteal muscle mass using BAM™ (Wildlife Pharmaceuticals, Windsor, CO). The fixed-dose BAM™ formulation contained 27.3 mg of Butorphanol, 9.1 mg of Azaperone, and 10.9 mg of Medetomidine per 1 ml of solution. BAM™ was administered based on estimated weight according to label directions. After injection, face blinds were applied, and deer were moved onto a tarp for processing. We placed a DuFlex medium ear tag (Valley Vet Supply, Marysville, KS) on the right ear of each deer providing contact info and a chemical warning. Animals were maintained in sternal recumbency with the head elevated above the rumen and nose oriented downward throughout processing. Time of injection was recorded as Time 0. Physiological data was collected at 5-min intervals for a 20-min period. This included respiration rate (in breaths per minute BPM) as determined by counting chest excursions, rectal temperature, and oxygen saturation

(SpO_2) using a SurgiVet v1030 portable pulse oximeter with a tongue sensor (Smiths Medical, Dublin, OH). Supplemental oxygen was always available in small canisters with a long-split cannula to be able to simultaneously supplement two deer from one canister (AirGas, Inc., Bladensburg, MD). Supplemental oxygen was used when oxygen levels stayed at or below 80% over 2 monitoring periods. During the processing period, we sexed each individual and estimated age by examining tooth wear and replacement (Severinghaus, 1949). Deer were categorized based on age as fawns (< 1 year old) or adult (≥ 1 year old). Each deer was examined for ticks by brushing back the fur then visually and tactilely searching primarily around the ears, head and anus (Luckhart et al., 1992). Ticks were opportunistically collected from the axilla and inguinal regions. Ticks were removed with forceps and placed into vials with 90% ethanol for later identification and pathogen testing. Every effort was made to maintain deer body temperature within normal limits. In warmer weather (ambient temperature over 15°C) a ground tarp was not used, and isopropyl alcohol was applied to the ears, axilla, and genital area. Ice was also placed around the abdomen of the individual. If body temperature decreased in cold temperatures, deer body temperature was normalized with space blankets and in extreme instances the rate of heat loss was slowed by having a team member maintain physical bodily contact with the deer under the blanket. After a minimum 20-min processing period, BAM™ was reversed with intramuscular administration of Atipamezole (25 mg/ml) and Naltrexone (50 mg/ml) (Wildlife Pharmaceuticals, Windsor, CO) in amounts based on initial injection amounts of BAM™. The reversal agent was given in the contralateral gluteal muscle mass from the BAM™ injection. Time to sedation and recovery were recorded. Deer were immediately released after recovery and monitored until they exited the area.

Trapping was cancelled if temperatures dropped below -12° C to ensure safety of captured individuals that may be stressed from the cold or poor body conditions. Trapping was also cancelled on extremely windy nights or during severe storms to ensure crew safety. The trapping protocol was approved by the United States Department of Agriculture Animal Care and Use Committee (IACUC approval #16-024) and University of Maryland (Board Reference XR-16-46, IRBNet ID 946395-1).

GPS Collaring Methods

Deployment

When tooth eruption ensured deer were >1 year of age and the deer neck was of sufficient size, deer were fitted with Globalstar Track L GPS/VHF radio collars from Lotek (Lotek Wireless Inc., Newmarket, Ontario, Canada). We deployed 50 of 51 tracking collars. The remaining collar was not deployed due to malfunction. We fitted collars with magnetic expansion belts provided by Lotek for male deer that allowed the circumference of the collar to expand with the deer's neck during the rutting season. Some collars were fitted with foam and duct tape to ensure the collar fit securely and reduce irritation (Collins et al., 2014). Collars were programmed to record a GPS location and timestamp every hour, and a third of this data was sent to an online database in real time. GPS fixes included latitude, longitude, and elevation location coordinate. Standard collar functions included recording metadata such as Dilution of Precision, Fix type (2D vs 3D), ambient temperature, and mortality. Globalstar Track collars have an estimated battery life of 18-36 months depending on deployment schedule and parameters.

Monitoring

Collared deer were monitored via ground radio telemetry for three consecutive days after capture then reduced to bi-weekly VHF locations for the remainder of the study. Telemetry was conducted to check the status of each collar rather than triangulate locations. The collars emitted 3 different radio beacon pulse rates notifying if it was active, in recovery mode (low battery), or mortality mode. GPS locations transmitted to Lotek Webservice online database were monitored every few days. Collars were equipped with a mortality sensor so that after 24 h of inactivity the collar would send a mortality alert via email and the radio beacon would change to Mortality mode. Collars were fitted with automatic drop off devices that automatically separate the collar to drop from the deer after a pre-programmed timer ended. Collars were relocated via radio telemetry and collected to extract the full data set upon dropping off.

Data screening

Often GPS data is ‘screened’ to remove possible erroneous locations. Metadata such as the number of satellites (fix type) or Dilution of Precision (DOP) which measures satellite geometry in relation to the GPS unit correlate with location accuracy of the GPS coordinate fix (D’eon & Delparte, 2005; Lewis et al., 2007). However, past studies have shown that DOP has limited ability to predict erroneous errors in the data (Bjørneraas et al., 2010; Ironside, Mattson, Arundel, et al., 2017). They produced minimal improvements in location error at the expense of data loss (Frair et al., 2010; Ironside, Mattson, Arundel, et al., 2017; Justicia et al., 2018). Removing more than 10-

15% of data may introduce bias into subsequent analyses (D'eon & Delparte, 2005). Location error can arise due to environmental conditions (cloud cover, vegetation density, terrain) or technical settings such as satellite-acquisition time, or animal behavior (e.g. burrowing, denning, diving) (Hansen & Riggs, 2008). Studies have shown that low collar fix rates can bias locational datasets if terrain or vegetation is disrupting satellites from communicating with collars resulting in a failed fix (Adams et al., 2013; Ironside, Mattson, Choate, et al., 2017; Lewis et al., 2007). Due to lack of consistency in screening data using only DOP, best management practices for screening GPS data involves determining specific collar average error or circular error probability (CEP). Then, based on terrain, study species, and objectives of the study researchers can remove selected data or remove nothing.

To test collar-specific location fix accuracy and fix acquisition rate (# attempted fixes/ # successful fixes) I placed one GPS collar at eight different areas of known location for at least three days. 'Known' locations were estimated using Garmin GPSMAP 64ST Handheld GPS (Garmin Ltd, Olathe, KS) waypoint averaging feature using at least 5 different locations per average. Testing locations spanned a gradient of canopy cover from open to dense (Table 2). Canopy Cover was measured using spherical crown densiometers. "Developed" cover areas refers to test sites where sky availability was obstructed from houses, buildings, urban structures whereas "Natural" cover areas refer to test sites where sky availability was obstructed by vegetation and tree canopies. Collars were placed at ground level and positioned in an upright manner. Fix rate was greater than 99% for all testing periods. Location fix accuracy or locational error (LE) was calculated by averaging the distance of collar GPS locations to the known position

(Table 2). Average LE was 9.65 m. Average collar error increased with decreasing sky availability due to increasing canopy cover or buildings obstructing the horizon. DOP was related to LE, but it explained very little of the variation ($F=634.6$, $p\text{-value}<.001$, Multiple $R^2 =.076$). Based on lack of convincing evidence to improve location error by screening data without risk of introducing bias and overall weak relationship between DOP and LE, I did not use DOP as a filtering method. However, GPS datasets were visually inspected and filtered for obvious outliers. For example, collars sometimes generated inaccurate fixes located at lat/long (0,0) in the Atlantic Ocean.

Chapter 2: Trapping white-tailed deer in suburbia for study of tick-host interaction

INTRODUCTION

Blacklegged ticks (*Ixodes scapularis*) are the vector of *Borrelia burgdorferi*, the causative agent of Lyme disease in North America. Vector-borne disease cases have tripled in just over a decade in the United States, with Lyme disease accounting for most of these cases (Rosenberg et al., 2018). In urban and suburban areas, the presence of domestic pets, proximity to human recreational areas, and interspersion of natural habitats and developed habitats increase the risk of exposure to pathogens or zoonotic diseases (Hollis-Etter, Anchor, et al., 2019).

White-tailed deer (*Odocoileus virginianus*) are a keystone host of the blacklegged tick, also known as deer ticks (Barbour & Fish, 1993). Surveillance of ticks on hosts is an important component of understanding the ecology of this species. Collecting biological samples for vector and disease monitoring for wildlife and human health is becoming more common and often requires live capture of the specific host species (Bloemer et al., 1988; Hollis-Etter, Anchor, et al., 2019; Merrill et al., 2018), but because capture of vertebrate hosts can be complicated; entomologists and disease ecologists have historically relied on ticks recovered from hunter harvests. However, recovery of ticks from these harvests is limited to hunting season regulations, subject to varying times of death, and limited access to the deer body which may be damaged by an arrow or bullet. In addition, parasite collections of hunter harvested animals may not permit assessment of a specific area like a neighborhood or park, especially if those target areas are urban or suburban where hunting seldom occurs.

Live capture of deer for wildlife research and management is costly and time demanding (Jones & Witham, 1995; Mayer et al., 1995). Several studies have evaluated the cost and labor required for trapping efforts. Reported costs varied immensely from $21/animal up to $3,200/animal depending on capture success, initial start-up costs, and labor hours (Bryant et al., 1993; Clark, 1995; Clark et al., 1981; Conner et al., 1987; Cosgrove et al., 2012; Jedrzejewski & Kamler, 2004; Jordan et al., 1993). Although costly and laborious, collection of active ticks and other ectoparasites are best done on live animals (Merrill et al., 2018; Rutberg et al., 2013; Tsunoda, 2014). Previous studies, using primarily cost and time, have evaluated if trapping programs were feasible as a population control strategy. Few studies have evaluated what factors affect capture success, but there are still major knowledge gaps. Given the cost and time investment, maximizing capture success is crucial.

In past studies, habitat characteristics, immediate land use, deer density, and deer behavior seemed to be main contributors to overall trapping success, but there is still lack of understanding how these factors influence trapping success (Garrott & White, 1982; Hiller et al., 2010; Webb et al., 2008). Mayer et al. (1995) reported better success rates when capturing deer at high densities. Generally, single bait sources had limited effect on trapping success in comparison to the habitat quality or home range location (Barrett et al., 2008; Campbell et al., 2006; Kilpatrick & Stober, 2002; Webb et al., 2008). Hiller et al. (2010) evaluated the effect of various environmental variables on capture success, reporting better capture probability in cold, snowy conditions in mid-western areas. However, in that study, deer restricted movements and foraging behavior when weather worsened. Barrett et al. (2008) reported local differences in capture success between sites, but no studies have formally evaluated habitat characteristics or differences in land use near trap sites that might affect capture success.

Direct comparisons between habitat characteristics from past studies proves difficult because the scale of study sites differ from 10ha-100,000ha and lack information on exact trap locations. Urban landscapes and habitats are highly variable, fragmented, and change drastically in short distances. Completing a small-scale analysis of land use near trapping sites to identify trapping hot spots can greatly inform research efforts to capture deer.

In this paper we document trapping success in two trapping seasons in a highly suburban area to evaluate habitat characteristics, land use features (land cover, crop fields, buildings, roads, recreational fields), and assess the relationship between weather variables (temperature, daily precipitation, daily snowfall, daily snow depth) and deer capture success. Given the high cost of trapping deer, the goal is to provide trapping protocols, guidelines, and considerations to make urban trapping more efficient, especially in instances when vector surveillance is the primary motivation for trapping.

METHODS

Study Area

The current study is part of an ongoing USDA-ARS area-wide suppression project of vector tick populations. A primary objective of the Areawide Tick Control Project was to collect data from and deploy GPS tracking collars on deer to analyze movements. White-tailed deer trapping was conducted in five county parks within the metropolitan zone of Howard County, Maryland (Fig. 1). The metropolitan zone of Howard County is characterized by heightened urban development and population density (Fig. 2). The metropolitan area of Howard County is characterized by 221 residential properties/km^2 with average lot sizes ranging from 0.05 ha to 3.3 ha, which falls within the parameters used to define suburban areas (Brown et al., 2005; Hansen et al., 2005).

Parks where trapping occurred ranged in size from 37 ha to 418 ha and estimated deer densities within the parks widely ranged from 12.5-174 deer/km^2 (Table 1). All deer density surveys were conducted with Forward Looking Infrared (FLIR) helicopter surveys by county Recreation and Parks personnel and county police. Cedar Lane Park, Middle Patuxent Environmental Area (MPEA), and Wincopin Trails/Savage Park area were trapped during the 2017 season and part of the 2018 season. Rockburn Branch Park and Blandair Regional Park were added to the trapping schedule in the 2018 season. All parks contained a mixture of developed amenities for recreational use, trails, and open space, which is undeveloped forest or grassland cover. Cedar Lane Park is a 37 ha area characterized by paved trails, athletic fields, picnic areas, and limited open space. The MPEA is a 418 ha park with an unpaved trail system. This park is largely open space maintained as mature forest stands and patches of protected early successional habitat. The Wincopin Trails System (115 ha) is directly adjacent to Savage Park (28 ha) and were analyzed as one unit. Together this area is characterized by paved and unpaved trails, mostly mature forest open space, and athletic fields located in Savage Park. Rockburn Branch Park is a 168 ha semi-wooded park with 14.5 km of paved pathways and unpaved trails. This park has several recreational fields and playgrounds including a disc golf course. Blandair Regional Park is divided into two properties by a major highway, totaling 119 ha. The southern property (58 ha) is mainly recreational fields and amenities. We trapped deer on the northern property (60.7 ha) which contains unpaved trails and primarily late successional open space.

The County Recreation and Parks Department implement deer population control at various parks via sharpshooting or managed hunts. Sharpshooting is conducted at night over bait piles by licensed marksmen. Managed hunts are restricted to shotgun and archery hunting by registered public participants. MPEA, Blandair (north), and Wincopin Trails area have had annual managed hunts since 1998, 2003, and 2014 respectively. Sharpshooting has occurred at Rockburn Branch Park, Savage Park area, and Blandair Regional Park since 2007. No population control is conducted at Cedar Lane Park (Table 1). All park properties are bordered directly by suburban neighborhoods and commercial buildings.

Trapping Methods

Deer were captured using drop nets (15.2m x 15.2m) and box traps (0.9m Width x 1.22m Height x 1.83m Length) (Wildlife Capture Services, Flagstaff, AZ) baited with whole kernel corn and apples. The 2017 trapping season was conducted from 1 February to 31 April, and the 2018 season was conducted 1 January to 31 April. Exact drop net placement within the site was selected to reduce interference with human recreational activity while maintaining ease of vehicle access. An area large enough for the net was cleared of large debris and special care was taken to remove glass, metal litter, and rocks. After pre-baiting for three days, the net was erected and monitored with a MOULTRIE® M-888 camera trap (Moultrie Feeders, Birmingham, AL) to determine group size and frequency of visits from deer. Once a net had deer visiting daily, a hunting blind was erected > 25 m from the net. During each trapping event technicians would wait in the hunting blind and drop the net via remote control once a deer was positioned under the net. In addition to drop netting, four box traps were placed in areas of high deer activity but also hidden from human view to reduce interference. After box traps were placed, the area inside and directly outside the entrance were baited. In addition to MOULTRIE® camera traps, we used SPYPOINT® Link-3G (GG Telecom, Indianola, IA) cellular cameras to monitor box trap activity allowing for immediate alerts when an animal was captured. Trap doors were tied open for approximately 2 weeks until deer became familiar with the bait and entered the trap daily. We modified our box trap trigger wires to stand at least 30 cm above the ground to avoid false triggers from non-target animals. Box traps were set in the evening and checked once a day at dawn. Box traps were not permitted to be set for capture while the parks were open due to concerns of public interference even though camera trap data showed deer activity at box traps throughout the day.

When an animal was identified under a drop net, the field crew activated the net, physically restrained the animals, and anaesthetized animals by hand syringe in the gluteal muscle mass using BAM™ (Wildlife Pharmaceuticals, Windsor, CO). The fixed-dose BAM™ formulation contained 27.3 mg of Butorphanol, 9.1 mg of Azaperone, and 10.9 mg of Medetomidine per 1 ml of solution. BAM™ was administered based on estimated weight according to label directions. After injection, face blinds were applied, and deer were moved onto a tarp for processing. We placed a DuFlex medium ear tag (Valley Vet Supply, Marysville, KS) on the right ear of each deer providing contact info and a chemical warning. Animals were maintained in sternal recumbency with the head elevated above the rumen and nose oriented downward throughout processing. Time of injection was recorded as Time 0. Physiological data was collected at 5-min intervals for a 20-min period. This included respiration rate (in breaths per minute BPM) as determined by counting chest excursions, rectal temperature, and oxygen saturation (SpO_2) using a SurgiVet v1030 portable pulse oximeter with a tongue sensor (Smiths Medical, Dublin, OH). During the processing period, we determined sex of each individual and estimated age by examining tooth wear and replacement (Severinghaus, 1949). Deer were categorized based on age as fawns (≤ 1 year old) or adult (> 1 year old). Each deer was examined for ticks by brushing back the fur then visually and tactilely searching primarily around the ears, head and anus (Luckhart et al., 1992). Ticks were opportunistically collected from the axilla and inguinal regions. Ticks were removed with forceps and placed into vials with 90% ethanol for later identification and pathogen testing. Every effort was made to maintain deer body temperature within normal limits. In warmer weather (ambient temperature over 15˚C) a ground tarp was not used, and isopropyl alcohol was applied to the ears, axilla, and genital area. Ice was also placed around the abdomen of the individual. If body temperature decreased in cold temperatures, deer body temperature was normalized with space blankets and in extreme instances the rate of heat loss was slowed by having team member maintain physical bodily contact with the deer under the blanket. After a minimum 20-min processing period, BAM™ was reversed with intramuscular administration of Atipamezole (25 mg/ml) and Naltrexone (50 mg/ml) (Wildlife Pharmaceuticals, Windsor, CO) in amounts based on initial injection amounts of BAM™. Twenty-minute minimum processing periods prevented renarcotization. The reversal agent was given in the contralateral gluteal muscle mass from the BAM™ injection. Time to sedation and recovery were recorded. Deer were immediately released after recovery and monitored until they exited the area.

Trapping was cancelled if temperatures dropped below -12° C to ensure safety of captured individuals that may be stressed from the cold or poor body conditions. Trapping was also cancelled on extremely windy nights or during severe storms to ensure crew safety. The trapping protocol was approved by the United States Department of Agriculture Animal Care and Use Committee (IACUC approval #16-024) and University of Maryland (Board Reference XR-16-46, ISBNet ID 946395-1).

Capture Success

We calculated trapping effort by counting all trapping events each day for both trapping methods. A drop net trapping event occurred when crew members activated a drop net regardless of capturing deer. For box trapping, a trapping event occurred when crews set the traps in the evening and checked them the following morning. Trapping effort accounts for multiple teams at different parks or the same park for drop netting each night. Most nights, we used two separate trapping crews working in two locations for drop netting to increase chances of successful captures during the season.

A successful trapping event occurred when at least one deer was caught under the drop net or in a box trap for that trap event. Only one successful trapping event was recorded even if multiple deer were trapped at the same time. On a few occasions, very small deer would be captured in a box trap but would be released without processing. Only deer that were trapped and processed (given immobilizing agents and an ear tag) were recorded as captures. We calculated capture success as the number of successful trapping events divided by the total trap effort for each park. We also calculated the number of deer captured per trap night as another measure of trapping success (Barrett et al., 2008; Cosgrove et al., 2012; Hiller et al., 2010; Morgan & Dusek, 1992; Naugle et al., 1995).

Spatial Analysis

We analyzed the habitat and land use characteristics immediately surrounding each trapping site. Box traps were excluded from habitat analysis because of very low capture rates. White-tailed deer in suburban areas exhibit high site fidelity and comparatively small home ranges (Kilpatrick et al., 2011; Porter et al., 2004; Rhoads et al., 2010; Swihart et al., 1995). Cornicelli et al. (1996) found that deer remained within 1 km of the trap locations. Therefore, we created a 1000 m radius buffer zone around the center of drop net trapping sites (Fig. 3). For those parks with multiple trap sites that had overlapping buffers, buffers were merged.

We chose several variables to include in the habitat and land use analysis such as, land cover, distance to agriculture, amount of buildings (residential properties, park facilities, businesses), recreational fields, as well as density of roads and streams. We measured Euclidean distance for important features such as roads, buildings, recreational fields, and streams to compare between trapping buffers and specific net locations. We evaluated habitat by quantifying the area of land cover or crop lands using land classifications schemes from National Land Cover Data (NLCD) 2016 and CropLand Data 2017-2018 (USDA-NASS, 2017; Yang et al., 2018). Four classification descriptions developed from the NLCD data set were grouped as follows: Urban cover

(Developed Open Space; Developed Low/Medium/High Intensity; Barren Land), Forest Cover (Deciduous Forest, Evergreen Forest; Mixed Forest; Woody Wetlands), Shrub/Grassland Cover (Shrub/Scrub; Grassland/ Herbaceous; Pasture/Hay; Cultivated Crops; Emergent Herbaceous Wetlands) and Water. Forest edge density, patch density, and landscape division index were calculated using Fragstats software by extracting forest land cover class from NLCD dataset for analysis (McGarigal et al., 2012; Walter et al., 2018). All county-level feature data was sourced from Howard County GIS Data Download and Viewer (Howard County GIS, 2015).

Statistical Analysis

Pearson's Chi-square test was used to evaluate the difference in capture success at each park. Weather variables were gathered from a local weather station during the period of trapping (Baltimore Washington International Airport, Baltimore MD, NOAA; https://www.ncdc.noaa.gov/cdo-web/datasets/LCD/stations/WBAN:93721/detail). Habitat and weather variables were tested for multi-collinearity using Spearman's correlation coefficients. Any pairs with $r \geq 0.7$, required that one of the variables would be removed from the model. A stepwise general linear regression model (GLM) using backwards elimination with replacement in package *Rcmdr* was used to evaluate the relationship between daily capture success, weather covariates and spatial attributes of the trapping sites (Fox & Bouchet-Valat, 2020). The response variable was assumed to have a binomial distribution, thus we used binomial family in the GLM model with logit link. The input model included *weather covariates*, *Julian day*, *forest edge density, percent grassland/shrub cover, percent recreational field cover, and road density* within the buffers. Model selection was completed based on AIC criterion. All analyses were performed using *stats* package in program R unless noted otherwise (R Core Team, 2020).

RESULTS

Trapping Results

We captured a total of 125 white-tailed deer (63 males, 62 females) during two trapping seasons using drop nets and box traps. In 2017 we captured 55 deer using drop nets and 4 deer using box traps. In 2018 we captured 63 deer using drop net and 3 using box traps. Overall, we captured 29 deer at Cedar Lane Park, 17 at Middle Patuxent Environmental Area, 29 deer at Wincopin Trails System, 20 deer at Blandair Regional Park, and 30 deer at Rockburn Branch Park The only box trap captures occurred at Cedar Lane (n=5) and MPEA (n=2). (Table 3). Six of seven box trap captures were male. Only 1 of 125 captured deer were euthanized on site due to a broken back leg sustained during trapping. No mortality was attributed to the use of immobilizing drugs. Deployment of GPS collars was an objective of our study, thus 50 of the 125 deer were monitored via radio telemetry for at least 30 days and no deaths were directly attributed to capture myopathy.

Average age of captured deer was 2.1 years old ± 1.0. We captured 26 fawns (≤ 1 year old), 22% of captures. We collected 149 ticks from 29 individual deer across four of five trap sites. We collected 2 species (*Amblyomma americanum, Ixodes scapularis*) of nymphs and adults (Table 4). We found 49% (n=73, Left = 44, Right = 29) of ticks on the ears, 29.5% (n=44) near the anus, and 21.5% (n=32) on other parts of the body. We progressively collected more ticks each month ranging from 17 collected during February and 91 collected during April.

Capture Success

Overall, 118 (94.4%) deer were captured with drop nets and 7 (5.6%) were captured in box traps. We did not have any recaptures with drop nets. However, on two occasions ear tags from previously trapped deer were found under the net most likely from deer that had escaped before they could be restrained. One recapture was recorded using box traps. For drop-netting, we recorded 62 successful trapping events out of 168 total trapping events. Of our successful trapping events, we caught 1.9 deer per event. We recorded 78 trapping events in 2017 and 90 events in 2018. We recorded 62 successful trapping events with drop nets for overall success rate of 36.9% (Successful trap events/total trap events) or 1.4 trap nights per deer or .70 deer per trap night (Table 3). Trapping success rates per park ranged from 28%-46% (Table 3). Pearson's Chi-square test shows that trapping success between parks was not significantly different based on the trapping effort at each park ($X^2 = 2.6086$, df = 4, p-value = 0.6253).

Net trapping effort increased until peaking around February 20th through March 27th and then slowly declined (Fig. 4). The distribution of successful captures each week is not significantly different from the distribution of trapping effort (Two-sample Kolmogorov-Smirnov test: D = 0.12976, p-value = 0.4461). Time of capture primarily ranged from 15:31-19:38 hours and averaged 18:00 hours (Fig. 5). On a few occasions we captured deer before dawn which required trapping crews to arrive at midnight and trap until morning if camera traps showed peak deer activity from 02:00-05:00 hours. Average ambient temperature at capture was 7.6° C and ranged from -11.6° to 22.9° C.

Results from analyzing landcover within buffer zones showed Blandair and Cedar Lane were the most developed areas with 52.8% and 52.7% urban cover, respectively. For most of the trapping sites <10% of the developed area was medium to high intensity or greater than 50% impervious surface. Cedar Lane was the only exception in which 15% of the developed area was medium/high intensity. MPEA and Wincopin Trails were the only trapping sites with majority forested cover (67.7%, 57.8% respectively). MPEA and Wincopin Trails also had the smallest area of shrub/grassland cover (4.8%, 3.2% respectively) whereas the other sites had 10%-20% shrub/grassland cover. Cedar Lane had the only habitat analysis buffer with legitimate cultivated crops accounting for 12.4 ha (3.04%) of the land. Crops varied year to year during the study but were either soybeans, corn or hay/alfalfa pastures. Cedar Lane had the shortest Euclidean distances to several features including major buildings and recreational fields whereas MPEA had the longest average distances for these features (Table 5**)**. The percent area of buildings within the buffer ranged from 3.8% at Wincopin Trails to 7.4% at Cedar Lane. Cedar Lane had the most area of recreational fields within the buffer (3.6%) as well. MPEA had the longest average Euclidean distance to roads among the trap sites (Table 5).

Correlation analysis indicated a maximum value of *r* (0.39 for *daily snowfall* and *daily snow depth*) between any two independent weather variables would not affect GLM procedures by including all four variables (*daily minimum temperature, daily precipitation, daily snowfall, daily snow depth*) (Hiller et al., 2010). However, many spatial variables were highly correlated ($r \geq 0.7$) limiting use in our regression models.

After removing one variable of any pair that highly correlated, the maximum value of *r* (0.62 for percent recreational field cover and road density) for any pair of spatial variables included in the model indicated that it would not affect GLM procedures. Only *daily minimum temperature* was selected as a significant predictor of capture success (95% CI [-0.119, -0.013], RMSE= 1.13, p= 0.016) (Table 6). Probability of capture increased with decreasing minimum daily temperatures (Fig. 6). Although snowfall and snow depth were not selected in the top model, both the second and third top performing models included snow related variables. Presence of snow may have had a positive effect on capture success.

DISCUSSION

Trapping Protocol

Generally, urban and suburban trapping operations require collaboration with state natural resource agencies to obtain any necessary permits. Likewise, local government agencies may request more involvement depending on the location and ownership of the trapping sites. Trapping will most likely occur in high-use public places (parks, natural areas, open space) that might require additional permits, consideration of public use, and interference with other management activities. Because of the unique nature of suburban deer behavior and suburban habitats, modifications to typical rural deer trapping protocols may also be necessary (Peterson et al., 2003). In some cases, local or state managed white-tailed deer or other hunts may have priority over trapping events. These factors make proper, thoughtful trapping protocols in urban and suburban areas even more crucial.

Public Perception and Engagement

The public's close proximity to trapping sites and other research operations in suburban and urban studies may prompt more public engagement (McCance & Baydack, 2017; Peterson et al., 2003). Researchers must anticipate the concerns and perceptions of residents in the area and be able to effectively convey project goals and operations to a diverse set of stakeholders. For the current project, we used multiple approaches for public engagement. Several attempts were made to inform the public about the goals of the project and anticipated management activities. The local natural resource agency organized several press releases to inform the public about the upcoming project and periodic updates throughout the project. Concurrently, crew members distributed project flyers and information pamphlets to neighboring homeowners near field sites. Conspicuous signage was placed at each trap to educate the public about the project and local codes prohibiting tampering with equipment. Because the overall project was related to Lyme disease control, local media coverage was also incorporated into the public outreach process. Nevertheless, face-to-face conversations were most successful in garnering interest and acceptance. As seen in other studies, our public contact was vital to the success of the project (Peterson et al., 2003).

While pedestrians would often walk by drop nets during operations, disturbance to trapping events from residents was not a major issue. In only one case did it significantly impact the trapping site. A drop net was vandalized during an inactive trapping period. Consequently, the net was not completely suspended, and a deer became tangled in the hanging net. Research staff were notified by residents and extracted the deer safely, but because of the lack of open space at this site suitable for trap set up and the observed vandalism, the site was removed from the study. Most issues encountered during trapping stemmed from equipment failure or user error.

Site Selection

It is important to evaluate the environment in which trapping will take place, especially in suburban areas. Sites will present challenges and unique features that need to be incorporated into the study design. Parks and open space areas may have limited space to place traps like drop nets. There may be suitable grassy areas, but often these are associated with recreational fields, parking, or ongoing habitat management. Alternatively, maintained open space may be a right-of-way such as power, sewer, or gas lines. It is important to understand the restrictions and requirements for use of this space, and to consult with the landowners or managers for access rights. Free-standing drop nets, which allowed more flexibility in trap placement without having to drive in support posts, should be considered in the initial study design (Peterson et al., 2003).

In general, all drop nets should be placed closer to the forest edge. Traps should be placed on level, dry ground free of debris including rocks and roots. Trees and shrubbery may need to be removed if suitable open space does not exist. Access to trap locations for transporting trap equipment is necessary. However, at the very least the biologists should be able to easily transport necessary equipment to the trapping location on foot within a few minutes after capture. To complicate this issue, many of the suitable trap locations in suburban areas are public lands. Increased use of these lands by vehicular traffic may provoke public complaints. Special care should be used in these areas to reduce traffic in wet or muddy conditions and avoiding trail deterioration.

Drop-Netting

Drop netting was the primary method to capture deer. We found drop netting to be a safe, quiet, and relatively efficient method for frequently capturing groups of deer (Conner et al., 1987; D'Eon et al., 2003; Jedrzejewski & Kamler, 2004; Peterson et al., 2003).

Drop netting may be less biased towards younger deer. Fawns only comprised 22% of all drop net captures which is less than the range reported for other studies using clover traps reporting 40%-66% of captures as fawns (Cosgrove et al., 2012; Haulton et al., 2001; Hiller et al., 2010; Naugle et al., 1995). We observed that smaller deer would enter under the net more readily only to be displaced by larger deer that dominate the bait pile. Having bait piles spread evenly enough to accompany multiple deer is imperative for catching groups at once. Many times, we dropped the net and deer caught just under the edge of the net would crawl out. A larger net would be beneficial to more effectively capture groups of deer, but we still recommend attempting to trap no more than 5 at a time (Conner et al., 1987; Pooler et al., 1997). At most, we caught four individuals during one trap event which requires at least five personnel on site to maintain safe handling and prevent increases in the likelihood of capture-related mortalities (Conner et al., 1987).

Disadvantages of drop nets include limited ability to select specific deer by sex, age, or other parameters. Drop nets are also conspicuous and must be left in the environment for deer to become acclimated, making them vulnerable to vandalism and weather-induced wear. Although drop nets are generally considered safe, netting poses a risk to antlered bucks that may get caught in the netting and can cause premature antler removal. Nets can also damage new antler growth if trapping is conducted into the spring or summer. Nets may also interfere with immediate positioning of deer in sternal recumbency. Immobilized deer need to be untangled and removed from the net in a timely manner. Proper drop net set up and maintenance is critical to success.

We captured most deer at dusk. Prime capture time seemed to occur later at heavily forested sites, but we still recommend setting traps before dusk. Our trapping protocol required the use of night vision or FLIR units to detect deer under nets. In the current study, daily use of parks by residents became more frequent towards the spring months, but throughout the project pedestrian or bike traffic was common in the parks from dawn until dusk. Sports activity was also a factor, and recreational field lights remained on into the night. The continuous presence of people in and around trapping areas prevented trapping from occurring until after the parks were closed, even though camera traps showed that deer occasionally visited box traps and drop nets during daylight hours. In less populated parks, it is recommended that traps are prepared, and operators hidden at least an hour before dusk. Deer at more developed parks seemed to exhibit less avoidance behavior to human activity. So, in heavily used parks, fifteen minutes to a half an hour may be enough due to deer habitation to human activity. Some nets were erected right next to walking trails, and late-night pedestrians would scare deer from approaching the net. However, deer at more urban parks would often return within 15-30 minutes after the pedestrian left the area. Deer at the more secluded, forested parks seemed weary towards human activity and would not return after being startled. Hunting blinds can help reduce motion of technicians, but we recommend setting blinds into the forest edge and hiding it well because often the blind would draw attention from approaching deer.

For trapping in rural areas, pre-baiting for a period of weeks is often recommended. It was our experience that in some areas deer came to bait the day after traps were erected. Deer should be given several days to acclimate to nets, and to learn that bait is routinely available, but long acclimation periods may not be necessary with suburban deer. White-tailed deer exhibited a degree of avoidance behavior to bait with other wildlife under the net. These interactions may have had an influence on trapping success. Birds, squirrels, raccoons, foxes, and rabbits were documented visiting trap sites to access bait. It was observed that attendance by foxes or raccoons at bait sites under drop nets would inhibit deer in the area from foraging under the net.

Box Trapping

Netted cage traps have the advantage of being lightweight, portable, fairly inconspicuous, and the only passive trapping option that can be placed in smaller locations. These traps can be set at specific times of the day, and placed in more wooded areas, not requiring open space. However, these traps do tend to capture younger deer, and male captures may occur less frequently than female (Hiller et al., 2010). Although a majority of our box trap captures were male. In our study, four box traps were used to supplement our primary trapping effort. Box trapping greatly increased our trapping effort and minimally increased capture success (7 captures). Most of the effort in box trapping was attributed to travelling from the field station to trapping sites and not from checking individual traps, which were often placed within 100 m of one another. In the future, we would either not use box traps or double the number of traps deployed to increase chances of capture without much effect on trapping effort (Jordan et al., 1993). Furthermore, we recommend using alternative bait to corn and apples in box traps as these received heavy non-target animal disturbance. Other trapping programs have used alternative baits such as hay/feed mixtures (Barrett et al., 2008).

Tick Collection Protocol

The distribution of ticks on their deer hosts is often congregated towards forelimbs, neck, and head allowing rapid assessment on tick abundance and reliable sampling zones for surveillance efforts (Kiffner et al., 2010). Individual deer in this study would be examined for ticks by one or more technicians but no formalized search effort was recorded. We primarily searched for and removed ticks on the ears, head, and anus but did a full body assessment and removed ticks from the axilla and abdomen region. However, maintaining anesthetized deer in sternal recumbency was a priority to ensure deer safety during processing which restricted search time on the underside of deer.

Adult ticks were found on ears, anus, and other parts of the body. Interestingly, nymphs were never found in the anus region. We recommend standard inclusion of the anal region in search efforts as it is easily accessible and lacks hair that might conceal attached ticks.

Nearly 90% (n=134) of removed ticks came from 15 deer from one park. Tick distributions within local environments can be highly patchy highlighting the need to sample at multiple locations for a better understanding of prevalence or abundance within communities (Pardanani & Mather, 2004).

Best results for tick collection occur on live or freshly deceased hosts since some parasites detach from expired hosts which may bias samples removed from roadkill and hunter harvested samples (Tsunoda, 2014). Trapping during peak tick activity season may increase the probability of collecting ticks on captured deer. We collected more ticks as the season progressed even though successful captures and trapping effort waned towards the end of the season. Unfortunately, higher ambient temperatures decrease capture probabilities and significantly increase capture myopathy and capture-related mortalities.

Capture Success

We cannot say one project was more successful than the other since many factors influence trap success both locally and regionally (Barrett et al., 2008; Cosgrove et al., 2012; Garrott & White, 1982; Hiller et al., 2010). Furthermore, comparisons of capture success should be considered loosely between different studies as some have used different trapping methods, different definitions of "trap nights", different definitions of "trap success", and often have incomplete data recorded on trapping effort for some seasons. Most studies report capture success as number of deer captured per trap night or number of trap nights per deer, but these studies heavily relied on box trapping which is not designed to capture multiple individuals at the same time like drop netting (Barrett et al., 2008; Cosgrove et al., 2012; Garrott & White, 1982; Hiller et al., 2010; Jordan et al., 1993; Morgan & Dusek, 1992; Naugle et al., 1995). If we use the number of deer per trap-night, our overall success rate is nearly 1.0 for some individual sites. However, a majority of trap nights we failed to capture deer. False triggers, released captures, non-target animal disturbance on traps was not accounted for in these estimates. Several trapping events were interrupted by electrical failures from incorrectly wiring the drop net or broken wires from fraying. Cold weather also drained power from the electronic equipment quicker than usual.

Since drop netting often catches multiple deer at a time we felt it was more accurate to calculate capture success as the {(number of successful trap events)/(total number of trap events)}. With this statistic our success rate for drop netting was 0.37 or at least one deer on 37 of 100 trap nights. When calculated as deer/trap night our capture rate is 0.70. We were successful 36.9% of the time and captured 1.9 deer per successful event. In a similarly designed, yet rural study, Conner et al. (1987) reported 48.7% (55 drops/113 trapping attempts) success rates using drop nets and caught 3.2 deer per drop. However, Conner et al. (1987) used larger drop nets in agricultural areas with reported deer densities of 36/km^2.

We were restricted to trapping on county owned land, but other studies have had success on private residences (Jordan et al., 1993, Peterson et al., 2003). These secluded properties, especially on larger lots (>1 ha) are prime refugia for urban deer. Including corporate lands and holdings, non-hunted state and county parks, nature preserves and easements, and municipal open space would be other potential trapping sites in suburban or urban areas (Ellingwood & Kilpatrick, 1995).

Spatial Analysis

Past papers quantifying and evaluating trap success typically have large study areas or generally describe the trapping locations. This is not as useful to urban managers where land use can change drastically in short distances. Our aim was to provide a successful urban/suburban trapping protocol, along with a small scale ≤1 km distance evaluation of habitat for urban trapping programs. The least successful trapping sites were MPEA (28.2% capture success, 0.38 deer/trap-night) and Wincopin Trails (35.3% capture success, 0.57 deer/trap-night) which were also the most forested (67.9%, 57.6% respectively) and had the least amount of forest edge habitat (Table 5). The most successful park was Cedar Lane (46.2% capture success, 0.92 deer/trap-night), and Rockburn and Blandair both had similar capture success 40% of trap events (0.94 deer/trap-night, 1.0 deer/trap-night respectively) (Table 3). Rockburn, Blandair, and Cedar Lane trapping sites had the most available shrub/grassland habitat. Cedar Lane and Blandair were the most urban with 52.7% and 52.8% urban cover respectively but also had the highest densities of forest/open edge habitat.

Even though contiguous forest is limited in Howard County, Maryland, and forest patches were small and interspersed, trapping success still had an inverse relationship with the area of forest cover. The suburban areas in our study with the best capture success exhibited higher amounts of forest edge habitat and not necessarily contiguous forest habitat. They had smaller habitat patches, denser building cover, and shorter distances to urban features such as buildings, roads, and recreational fields. This is certainly something managers and researchers should keep in mind when selecting trapping sites. Furthermore, because white-tailed deer home range sizes decrease in size when there is more forest edge habitat, managers will likely have higher deer densities in these highly fragmented Parks (Walter et al., 2018). Those higher densities, coupled with human habituation, may have led to the higher capture success in this study.

Weather

Poor weather (i.e. below freezing, snow) has been linked to decreased activity in white-tailed deer. This is an energy conservation strategy when natural forage is low and may not be as advantageous when artificial food sources are readily available because of trapping (Moen, 1976; Taillon et al., 2006; Verme, 1973). Deer may increase activity and movement towards a bait pile or artificial food source during similar conditions since it is easily accessible food (Taillon et al., 2006). We documented increases in probability of capture as daily minimum temperatures decreased. Hiller et al. (2010) found similar effects of minimum temperatures on capture success in more northern latitudes; however, we did not detect any significant effect of snow on capture success in our model, but snow was included in the second and third top performing model. Maryland has less severe and infrequent winter storms and these covariates may be less reliable in this region for predicting capture success or we lacked statistical power to demonstrate the relationship. Other weather covariates not accounted for in our analysis, such as wind velocity or barometric pressure, may influence capture success as well.

Trapping Considerations Summary

If live trapping white-tailed deer is necessary to reach management or research objectives in urban or suburban areas, we recommend the following:

- Develop significant public outreach before fieldwork occurs

- Connectivity between parks and edge density habitat patches will greatly influence deer distribution and behavior throughout the area
- Develop an urban/suburban specific trapping protocol, with concentrated drop net trapping and preparations for significant pedestrian/human interactions
- Small, human-developed parks are often the most productive trapping sites
- Cold weather and snow likely drives trapping success, followed by presence of recreational fields
- When collecting vectors, such as ticks, as appropriate, do full body searches

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SUPPLEMENTARY MATERIAL

A table listing supplies used in the deer trapping protocol is provided in Appendix B. It includes Item, Purpose, Example and Grouping.

Chapter 3: Home range and movement characteristics of white-tailed deer in suburban Maryland

INTRODUCTION

Understanding the ecology of white-tailed deer in urban and suburban settings has become a main topic in wildlife research as managers try to grapple with overabundant deer populations. High densities of deer can lead to increased risk of deer-vehicle collisions (DeNicola & Williams, 2008; Hussain et al., 2007), vegetation and crop damage (Rooney & Waller, 2003), and disease transmission to other deer, humans, and their pets (Hollis-Etter, Anchor, et al., 2019; Hollis-Etter, Montgomery, et al., 2019; Walter et al., 2011). Past research has highlighted findings on home ranges or movements (Grund et al., 2002; Kilpatrick & Spohr, 2000; Piccolo et al., 2000; Rhoads et al., 2010), resource use (Grovenburg et al., 2010), as well as findings on population management (Porter et al., 2004), hunting (Crawford et al., 2018; Storm et al., 2007a), sterilization (Gilman et al., 2010), and disease transmission (Hollis-Etter, Anchor, et al., 2019; Walter et al., 2011). White-tailed deer are an adaptive species known to inhabit rural (Walter et al., 2009), exurban (Rhoads et al., 2010; Storm et al., 2007b), suburban, and urban areas (Etter et al., 2002; Kilpatrick et al., 2011; Porter et al., 2004; Potapov et al., 2014; Urbanek & Nielsen, 2013). Research shows that as fragmentation and forest edge habitat increase, white tailed deer home ranges tend to shrink (Dechen Quinn et al., 2013; Walter et al., 2018).

White-tailed deer are a prolific species in the eastern United States, often exhibiting higher densities in and near suburban landscapes (Dechen Quinn et al., 2013; Walter et al., 2018). Suburban landscapes are characterized by a network of residential neighborhoods, schools, businesses, and small patches of open space or undeveloped land, which provides ample habitat for white tailed deer (Potapov et al., 2014).

Fragmented patches of open space, ornamental plantings, and supplemental feeding provide practically year-round palatable vegetation (Williams & Ward, 2006). Deer find cover in smaller, dense undeveloped patches and movement is enabled between these patches via private properties (residences or businesses), road rights-of-way, and riparian areas (Grund et al., 2002; Kilpatrick & Spohr, 2000a, 2000b). Deer are often protected from hunting by local firearm restrictions and no hunting zones (Kilpatrick et al., 2011). Given reduced natural predation, deer-vehicle collisions have been documented as the leading cause of mortality for deer in suburbia followed by hunting or culling in hunted populations (Etter et al., 2002).

Suburban deer home ranges are typically small but can vary widely between individuals and seasons (Etter et al., 2002; Grund et al., 2002; Henderson et al., 2000; Kilpatrick et al., 2011; Kilpatrick & Spohr, 2000b, 2000a; Porter et al., 2004). Suburban deer have high site fidelity (Grund et al., 2002; Porter et al., 2004), high juvenile survival rates (Etter et al., 2002; Storm et al., 2007b), and use residential areas for foraging and cover with increasing intensity during winter months (Grund et al., 2002; Kilpatrick et al., 2011; Kilpatrick & Spohr, 2000b; Swihart et al., 1995). Often, home range size decreases as age increases (Webb et al., 2007), and use of core areas was documented as greater during the day in suburban habitats with peak hours of activity occurring at dawn and dusk (Kilpatrick et al., 2011; Rhoads et al., 2010; Walter et al., 2011).

It is possible that the variations in movements and behavior in highly populated areas could translate into increased risk of zoonotic disease. Deer are keystone hosts for adult ticks, and they can carry a multitude of other infectious agents to people, pets, and livestock (Brook et al., 2013; Hollis-Etter, Anchor, et al., 2019; Miller et al., 2003). Deer have adapted to thrive in close proximity to humans, which increases the risk of zoonotic disease (Hollis-Etter, Anchor, et al., 2019).

There are few existing studies quantifying deer movements in suburban areas. Some papers show deer exhibit slight avoidance or moderate use of residential areas (Grund et al., 2002; Kilpatrick et al., 2011; Kilpatrick & Spohr, 2000b, 2000a; Storm et al., 2007b; Swihart et al., 1995), but all studies found some level of use of residential developments was present and increased use-intensity during winter. Approximately one third of deer home ranges comprised neighborhoods, and core ranges incorporated a greater density of buildings than full home ranges (Grund et al., 2002; Kilpatrick et al., 2011). Average number of houses in core ranges was 5.2-17.6 (Kilpatrick et al., 2011; Kilpatrick & Spohr, 2000b); and housing densities in homes ranges were between 0.13 and 1.7 buildings/ha (Kilpatrick & Spohr, 2000b; Storm et al., 2007b).

The objective of this study was to build on past knowledge of suburban residential land use using high resolution telemetry data and updated home range estimation techniques. More specifically, we characterized suburban land use within home ranges, quantifying and evaluating use of residential properties based on the potential for increased tick dispersal by deer. Better quantified information on suburban yard and neighborhood use by deer can inform managers tasked with managing deer populations that inhabit private land.

METHODS

Study Area

This research was conducted within five county parks in Howard County, Maryland (Table 1). Howard county is situated in the Piedmont Plateau region of

Maryland (Maryland Department of Natural Resources (MDNR), 2016), approximately 18 miles south of Baltimore, MD and 27 miles north of Washington D.C. Howard County has a human population of approximately 325,690 people and is 650 km^2 for 501 people per km^2 (U.S. Census Bureau, 2019). All five study sites were within the metropolitan boundary of Howard County, which is characterized by heightened urban development and population density (Fig. 2). Within the metropolitan zone, there was 9.64 persons/ha versus more rural western portion of the county with 1.24 persons/ha (Kraft, 2008). The western portion of the county, outside of the metropolitan zone, which makes up 60% of the land was largely farmland and forest (Howard County Department of Planning and Zoning, 2018). On average annual rainfall was 1.09 m and annual snowfall was 0.58 m (Kraft, 2008). In winter, the average temperature was 0.78 °C and the average daily minimum temperature was -4.9 °C. In summer, the average temperature was 22.9 °C and the average daily maximum temperature was 29.6 °C (Kraft, 2008). Soil across the state is predominately sassafras sandy loam and high proportions of clay (Kraft, 2008). Soils in the eastern portion of the county have been highly disturbed due to development and urban sprawl (MDNR, 2016; Kraft, 2008). Many of the soils in the county are well suited to intensive agricultural production. Corn and soybeans were the primary crops grown (USDA NASS, 2017). Forest cover within the study sites was predominantly oak (*Quercus spp.*), hickory (*Carya spp.*), and Tulip poplar (*Liriodendron tulipifera)* in the overstory. The understory was often dominated with invasives such as Autumn olive (*Elaeagnus umbellate*), Japanese honeysuckle (*Lonicera japonica*), and multiflora rose (*Rosa multiflora*). However native species such as *Rubus spp*., maple (*Acer spp),* and black cherry (*Prunus serotina*) were common (Kraft, 2008).

Deer Densities

Deer density was estimated within various park properties by county police and Recreation and Parks personnel using Forward Looking Infrared (FLIR) helicopter surveys. Deer densities within the parks ranged widely from 12.5-174 deer/km^2 (Table 1). Deer density was not calculated for Cedar Lane Park in 2017 or 2018. The County Recreation and Parks Department implement deer population control at various parks via sharpshooting or managed hunts. Sharpshooting was conducted at night over bait piles by licensed marksmen. Managed hunts were restricted to shotgun and archery hunting by registered public participants. Middle Patuxent Environmental Area, Blandair Regional Park (north), and Wincopin trails area have had annual managed hunts since 1998, 2003, and 2014 respectively. Deer in Savage Park (directly adjacent to Wincopin Trails area), Rockburn Branch Park, and Blandair Regional park (north) have been managed by sharpshooting since 2007. Managed hunts were not conducted in Cedar Lane Park (Table 1).

Trapping Methods

Deer were captured using drop nets (15.2m x 15.2m) and box traps (0.9m Width x 1.22m Height x 1.83m Length) (Wildlife Capture Services, Flagstaff, AZ) baited with whole kernel corn and apples. In addition to drop netting, four box traps were placed in areas of high deer activity but also hidden from human view to reduce interference. Box traps were set in the evening and checked once a day at dawn.

When an animal was identified under a drop net, the field crew activated the net, physically restrained the animals, and anaesthetized animals by hand syringe in the gluteal muscle mass using BAM™ (Wildlife Pharmaceuticals, Windsor, CO). The fixed-dose BAM™ formulation contained 27.3 mg of Butorphanol, 9.1 mg of Azaperone, and 10.9 mg of Medetomidine per 1 ml of solution. BAM™ was administered based on estimated weight according to label directions. After injection, face blinds were applied, and deer were moved to a ground tarp for processing. During the processing period, we sexed each individual and estimated age by examining tooth wear and replacement (Severinghaus, 1949). Lotek GlobalStar L collars were deployed on individuals deemed greater than 1-year-old with sufficient neck circumference of ≥30.0 cm. Often collars were retrofitted with foam and tape to reduce the collar shifting on the neck and subsequent irritation (Collins et al., 2014). GPS collars were programmed to stay on for 116 weeks and take one location every hour. After a minimum 20-min processing period, BAM™ was reversed with intramuscular administration of Atipamezole (25 mg/ml) and Naltrexone (50 mg/ml) (Wildlife Pharmaceuticals, Windsor, CO) in amounts based on initial injection amounts of BAM™. Based on manufacturer recommendations, a reversal of 0.5 ml (25 mg) of Naltrexone was recommended for all set doses of BAM™, and for every 0.5 ml of BAM™ administered, at least 1.0 ml (25 mg) of atipamezole be administered.

Deer were immediately released after recovery and monitored until they exited the area. Collared deer were monitored via VHF for the first three days after deployment and then reduced to biweekly relocations. The trapping protocol was approved by the United States Department of Agriculture Animal Care and Use Committee (IACUC approval #16-024) and University of Maryland (Board Reference XR-16-46, ISBNet ID 946395-1).

Analysis

Home ranges were created using Autocorrelated kernel density estimators with *ctmmweb* app in R (Calabrese et al., 2016; Dong et al., 2018; Fleming et al., 2015). Annual home ranges were created for each individual that had at least 10 months of data available from the deployment date (Kilpatrick et al., 2011). Summer (Jun 21st-Septmeber 22nd) and winter (December 21st-March 20th) were created only if the dataset from each deer fell completely within these ranges. We created 95% and 50% home range contours. Movement models to develop home ranges were calibrated with 10 m error. Autocorrelation structure of each dataset was visualized using variograms. Behavior and shape of the variogram at short, intermediate, and later time lags can provide insight on quality of model fit (Calabrese et al., 2016). Calabrese et al. (2016) recommend that any variogram which does not reach an asymptote at increasing time lags be removed before analysis due to change in autocorrelation structure resulting in inaccurate home range estimates (Calabrese et al., 2016). White-tailed deer are typically range-resident species but do exhibit migratory or range shifting behavior in this region, which would result in a non-asymptotic variogram and poor home range estimation (Calabrese et al., 2016; Rhoads et al., 2010). Thus, for this study, any variograms that did not appear to reach an asymptote at later time lags were removed (Calabrese et al., 2016; Fleming et al., 2014). Datasets stemming from remote uploads were analyzed with optimal weighting enabled because these datasets often had highly variable gaps in sampling frequency (Fleming et al., 2018).

Land cover and land use were quantified within the 95% and 50% home range contours using Tabulate Area tool in ArcGIS and National Land Cover Dataset 2016 (Yang et al., 2018). Land cover classifications are used as defined by Yang et al. (2018), but “Woody Wetlands” and “Emergent Herbaceous Wetlands” were reclassified into “Wetlands”. We used a land use layer from Howard County GIS database to quantify ownership and proportion of residential land within the home ranges (Howard County GIS, 2015). Groupings from the land use layer were reclassified as follows: Residential (E.g. single-family attached, single family detached, condo apartments, rental apartments, mobile homes), Government and Institutional Land (E.g. schools, cemeteries), Commercial Land, Industrial Land, or Undeveloped Land (Residential, Government, Commercial, Industrial). We counted number of residential properties within the core ranges using Spatial Join tool in ArcGIS with the land use cover layer. Residences were grouped into single residence properties (e.g. detached houses, townhouses) and multiple residence properties (e.g. apartments, condos). While a separate category, individual multiple residence properties were counted as being only one residence even though one property may contain 20 residences, as would be found in an apartment building. We measured the distance from GPS locations of deer to nearest residential buildings using the Near Table tool in ArcGIS and compared those distances based on time of day and time of year. These same metrics (proportion of landcover, proportion of land use cover, and building density) were calculated around each trap site to compare for differences among specific parks. Deer in this study were found to move an average of 2148 m a day which was used as the buffer radius size to demarcate individual study areas. Results are available in Appendix C.

We also analyzed hourly movement rates (distance, relative turning angle, speed) of deer. The first 14 days of each dataset was removed from the analyses to reduce potential bias caused from capture and collaring (Dechen Quinn et al., 2012). We measured the Euclidean distance and time between each successive points to determine speed (meters/hour). Time was converted into "suntime" using function *sunTime* in R with Columbia, MD (39.2037° N, 76.8610° W) as the reference point (Ridout & Linkie, 2009). This allowed for better insights into diel patterns since suntime reflects the suns position in the sky (Nouvellet et al., 2012). We then grouped movement rates into Day, Night, and Crepuscular categories to determine temporal patterns in movement using package *maptools* (Bivand & Lewin-Koh, 2020; Webb et al., 2010). Day was classified as the time within sunrise to sunset, and night was considered from the end of astronomical sunset to beginning of astronomical sunrise using NOAA definitions of twilight. Crepuscular periods were occurred during astronomical sunrise and sunset, which begins in the morning and ends in the evening when the geometric center of the sun is 18° below the horizon. Data was grouped into Winter, Summer, and Annual time periods for analysis. Any deer that had more than one movement (step length) within the time category was included. Only movements with time lags of 1 hour ± 3 minutes were included in analysis because decreasing fix rates can bias estimated distances (Massé & Côté, 2013; Pépin et al., 2004; Rowcliffe et al., 2012). We also used package *adehabitatLT* to calculate relative turning angle for deer movement paths (Calenge, 2006). Output was in radians ranging $-\pi - \pi$ with values of 0 corresponding to straight movement and $-\pi/\pi$ correspond to turning directly around relative to previous movement path. We selected GPS points within Residential and Parks/Open Space land use classes using Howard County land use layer to include for comparison in the movement analysis. We then selected GPS points that had at least one consecutive point, either before or after, within the same land use class because we wanted to analyze speed and turning angle for segments of movement paths completely within the same land class.

Statistical Analysis

Normality of data was checked using the Shapiro-Wilks test. We used Wilcoxon rank sum test to compare grouped averages of home range size, number of residential properties within ranges, distance to residential properties, habitat within ranges, and movement rates within residential and parks/open space land classes. We grouped data by season and sex depending on the analysis. Movement rates were averaged for individuals before analysis. We used two-sample Kolmogorov-Smirnov test in package *dgof* to compare differences in distribution of relative turning angles between residential and parks/open space movement (Arnold & Emerson, 2011). We used Kruskal-Wallis rank sum test in package *onewaystats* to compare differences in movement rates and distance to buildings between the three time of day categories (Dag et al., 2018). Significant results were then tested with Dunn's post hoc test to determine which groupings differed (Dinno, 2017). We used package *ggplot2* and *stat_smooth* function with gam method to produce movement rates and distance to buildings figures (Wickham, 2016). Results were considered significant if $p<0.05$. All statistical analyses were completed in package *stats* using program R unless otherwise noted (R Core Team, 2020).

RESULTS

Deer Data

A total of 125 deer were captured between 2017 and 2018 trapping seasons. We collected data from 53 (35 Females/ 18 Males) collared deer. Average age of collared deer was 2.7 ± 0.9 (range 1-5). We collected data from 15 deer at Cedar Lane Park, 10 deer at Blandair Regional Park, 9 deer at Middle Patuxent Environmental Area, 9 deer from Rockburn Branch Park, and 10 deer at Wincopin Trails System. We possessed 51 collars and deployed 50 collars. Four of these collars were deployed on multiple deer. We recovered 26 of 50 collars from the field after dropping off or mortality events and recovered the full store-on-board dataset. Malfunctions and drained batteries prevented recovery of the remaining 24 collars however a subset of data was transmitted to an online database in real time. Collar malfunctions occurred in 31 of 51 collars. We recovered 7 collars after failure by happenstance while conducting fieldwork, from hunter harvested deer, or other mortality events. Malfunctions caused collar battery to die prematurely before scheduled drop off date or drop off mechanism failed to separate. There were 15 recorded mortalities of collared deer. Roadkill was the greatest source of mortality (n=8), followed by hunter harvest (n=5) and unknown mortality sources (n=2). We obtained 219,839 GPS locations from recovered collar store-on-board datasets and 54,145 GPS locations from remotely uploaded datasets.

Home Range

Home range size was variable across sexes and seasons. Annual and Winter home and core ranges did not differ among parks, but summer ranges were statistically different (home range: chi square: 13.27, df=4, p-value=.01; core ranges: chi-square= 13.68, df=4, p-value=.008). Cedar Lane was different than Rockburn and Blandair parks often producing larger summer home ranges. Data was combined for parks due to lack of sample size sufficient for statistical analysis. Combining years, female (n = 10) annual 95% home ranges averaged 106 ha ± 96.2 and male (n = 4) annual 95% home ranges averaged 317 ha ± 184. Female annual 50% core ranges averaged 20 ha ± 17.2 and male annual 50% core ranges averaged 43 ha ± 31.1 (Table 7). Male annual home ranges and core ranges were not significantly different than female ranges (W = 7, *p*-value =.076; W = 8, *p*-value = 0.11, respectively). Summer home and core ranges were significantly smaller than winter ranges for both sexes (Table 8).

Deciduous forest cover and Developed Open Space are consistently the predominant cover classes within deer home ranges across seasons and years. Deciduous forest cover comprised approximately 42-56% of range areas (Fig. 7). Next predominate habitat cover type was developed open space comprising 21-27% depending on season and sex. Developed Space of Low intensity is the third most prevalent cover class within home ranges ranging from 6.5-14%. The remaining percentage is primarily attributed to developed medium intensity space and woody cover such as mixed forest or shrub/scrub land, and grassland cover such as pasture. Land cover composition for specific park buffer zones is available in Appendix C Table C.1.

Parks/Open Space and Residential land use classes were the predominate land use classes within home ranges across all years and seasons (Fig. 8). Minor land use classes included Government/Institutional land (e.g. school grounds, cemeteries) and undeveloped residential land. A higher proportion of parks and open space were found within core ranges whereas more residential land was within the home ranges (Fig. 8). Parks and open space maintained the majority of land use within the home ranges but more residential land was used during winter months, however this interaction was not statistically significant (male home range: W = 22, *p*-value = 0.3; male core range: W = 15, *p*-value = 0.08; female home range: W= 63 , p-value=0.32, female core range: W=74, p-value= 0.64). See Appendix C Table C.2 for specific park buffer zone land use composition.

Average number of residential buildings within deer annual 50% core ranges for females (n = 10) and males (n = 4) was 71.3 and 129, respectively (Table 9). There were significantly more residential properties located within winter than summer home ranges for combined sexes (D = 0.44196, *p*-value = 0.045), but no significant difference was detected for males and females separately. Specific park buffer zone residential building density is available in Appendix C Table C.3.

Movement

There were diel and seasonal trends in white-tailed deer movement for both sexes (Figs. 9 & 10). White-tailed deer hourly movement rates were significantly different depending on time of day for both sexes (females: chi-square=16.8, df= 2, *p*-value =.00023; males: chi-square:12.39, df=2, *p*-values = 0.002; Table 10). Dunn's post hoc test identified that crepuscular movement was greater than day or night movement, but day and night movement was not significantly different (Table 10). Movement averages were greatest during crepuscular periods and lowest during daylight hours (Table 11). Female overall hourly movement (n = 15) averaged 75.5 m/h ± 117 during the day and 88.4 m/h ± 129 at night and 124.6 m/h ± 152 during crepuscular periods. Male annual hourly movement (n = 12) averaged 78.5 m/h ± 143 during the day and 108.5 m/h ± 180 at night and 133.7 m/h ± 183 during crepuscular periods. Winter hourly average movement rates were generally greater than summer movement rates for both sexes

(Table 11). Movement rates did not statistically differ for males and female deer depending on their location in residential land or Park/Open Space (n=12, W=83, p-value=0.55; n=15, W=127, p-value= 0.57, respectively). Average female hourly movement in Parks/Open Space was 71.3 m/h ± 112 (median = 30.8 m/h) and slightly faster in Residential land 73.5 m/h ± 106 (median= 33.1 m/h). Average male hourly movement in Parks/Open Space was 73.8 m/h ± 127 (median = 29.3 m/h) and greater in Residential land at 89.2 m/h ± 148 (median = 33.9 m/h). Distribution of relative turning angles did not differ for male or female movement within land use classes (D=.0093455, p-value=0.41; D=.0092471, p-value=0.18, respectively). Examining the distribution of turn angles there was a slight trend for movement to be less tortuous and more straight/direct in Residential areas, especially for male deer (Fig. 11).

Similar to movement rates there were trends in diel and seasonal distances of deer locations to residential buildings (Figs. 12 & 13). However, white-tailed deer distance to residential buildings was not significantly different during day, night, and crepuscular periods (females: chi-sqaured=0.94553, df=2, *p*-value =0.62; males: chi-square=0.15398, df =2, *p*-value =.9259). On average, females (n = 33) were found 88.8 m ± 91.2 from residential buildings during daylight hours, 79.5 m ± 92.7 during nighttime, and 88.7 m ± 93.1 during crepuscular periods. Males (n = 18) were found on average 126 m ± 119 from residential buildings during daylight, 114 m ± 136 at night, and 117 m ± 122 during crepuscular periods. Averages grouped by season are available in (Table 12). There was no significant difference in female or male distances to residential buildings (W=271, p-value = .6185).

DISCUSSION

Home Range

Home range sizes were comparable to those reported for white-tailed deer in developed areas. They were larger than past studies involving urban/suburban deer (Etter et al., 2002; Grund et al., 2002; H. J. Kilpatrick et al., 2011; H. J. Kilpatrick & Spohr, 2000b, 2000a), but are smaller than other studies in rural or exurban areas (Storm et al., 2007b; Walter et al., 2009). We see a high variability in home range size across individuals (H. J. Kilpatrick et al., 2011). There was a 330 ha difference and 690 ha difference between smallest and largest home range for summer and winter, respectively. Individual variability can arise from factors such as age, sex, social status, or other population demographic factors like density or sex ratio. Each of these factors can influence individual space use on the landscape during biological seasons such as rut or parturition, making them more likely to defend territory or seek new grounds which would influence home range size. Walter et al. (2011) recorded inverse relationship between home range size and age.

Home and core range sizes significantly differed between season (Dechen Quinn et al., 2013; Etter et al., 2002; Grund et al., 2002; Rhoads et al., 2010; Storm et al., 2007b). Reduced summer home ranges were expected based on past research and it may be attributed to parturition in which females reduce movement or the increase in forage availability enabling deer to travel less to obtain necessary resources (Walter et al., 2011).

Our home ranges were larger when compared to other papers on urban/suburban deer, but we demonstrated similar patterns in home range dynamics and seasonal dynamics. Most of the past research used fixed or adaptive kernel home range estimation methods. Here we are using autocorrelated kernel density estimators because of autocorrelation in the data. AKDE accounts for autocorrelation from large, high-resolution (e.g. hourly) location datasets and generates a larger, more accurate estimation of home range size than traditional kernel methods (Fleming et al., 2014; Fleming et al., 2015). When the data is autocorrelated traditional KDE methods will underestimate true space use (Fleming et al., 2014).

Deer home ranges in our study sites have higher housing densities than past research. Studies in the literature report their study sites as suburban, but they typically do not specifically define suburban. We base our suburban classification on Theobald's (2001) definition of 0.247-2.47 units per ha. The highest housing density reported for a study site was Kilpatrick & Spohr, (2000a) averaged 1.7 dwellings per ha. Whereas Howard County metropolitan area has an average 2.0 residential buildings per ha.

Although fragmentation creates edge habitat, which deer prefer, they still exploit a majority of forest cover in suburban areas. Dechen Quinn et al. (2013) also found deer home ranges to be approximately ~50% forest cover. Dechen Quinn et al. (2013) also found agricultural land was the next most common land class within deer home ranges, but for our study the immediate surroundings from the study sites had small amounts of crop land and more residential land.

Many past studies have examined habitat selection and space use of white-tailed deer. The research shows that white-tailed deer are adaptable to a variety of habitats but prefer a mixture of forest and grassland cover (Grund et al., 2002; Potapov et al., 2014). However, knowing the habitat use and whereabouts of suburban deer does not do much unless managers can access them for management activities. Many management activities such as population control, demographic surveys, integrated pest management treatments, or disease management are limited to public spaces often in state or county parks and green spaces.

Knowing the proportion of public and private land within deer ranges will help managers most effectively manage the deer herd. Management has largely been focused on public properties, but according to this study, a major portion of deer space use is on private lands (homeowner properties, commercial/corporate land holdings). Focus in management is shifting to include or involve private residences (Peterson et al., 2003), but effectiveness of management could be greatly reduced if private land use by deer is not accounted for and these deer are not being targeted for management.

White-tailed deer in this study predominantly used land zoned as parks, open space, or green space; however residential land comprised a substantial portion of home range and core range areas. Depending on season, the proportion of parks and open space in the ranges spanned 49-65% (range: 12-100%) and winter ranges had the least amount of parks, open space land. Depending on season, residential land comprised 27-43% (range: 0-83%) of land within home ranges. Governmental/Institutional and Undeveloped Residential land were the other two minor land use classes within deer ranges (Fig. 8). Governmental/Institutional land can refer to public school grounds, cemeteries, etc. Managers would also need explicit permission to access these properties for management activities. Similarly, Grund et al. (2002) found that deer home ranges encompassed 24%-

50% of residential land, except during one severe winter when space use on residential landscapes was intensified. Kilpatrick & Spohr (2000a) determined that 22.9-33.9% of home range area was within residential development depending on time of year, and home ranges contained more residential land than core ranges. Kilpatrick & Spohr (2000a) detected a significant change in residential development within core ranges between winter and summer months however this was not detected at the home range level. In our study, no difference was detected in summer and winter residential land use within home or core ranges (Table 8). However, both core ranges and home ranges had slightly more residential land and less parks/open space contained during the winter months. Core areas in our study were concentrated on park land highlighting the importance of hiding cover for deer whereas the greater home range encompassed more residential space because it represents foraging bouts that leave the park space (Kilpatrick & Spohr, 2000b).

Similarly, other studies have highlighted the pattern of residential space use increasing during winter months (Grund et al., 2002; Kilpatrick & Spohr, 2000b; Storm et al., 2007b). Deer may be exploiting fertilized ornamental plants that have different phenology than native vegetation providing palatable forage during winter months (Williams & Ward, 2006). Supplemental feeding or baiting by residential homeowners was common throughout the study area which may attract deer to residential areas. Additionally, the availability of bird feed, food scraps or unfenced gardens provide easy food sources for deer during winter months (Grund et al., 2002; Kilpatrick & Spohr, 2000b).

On average, male ranges contained more residential properties than females, which may be an artifact of larger range sizes. The number of properties within core ranges increased during the winter months for both sexes. Kilpatrick & Spohr (2000b) and Storm et al. (2007b) found more homes within core areas during winter than fawn-rearing season, but these averages were less than 10 houses within core areas. Kilpatrick et al. (2011) completed a study and found housing density within core ranges to span 1.1-2.1 houses/ha but average number of homes within ranges was approximately 17. Kilpatrick et al. (2011) study area did not report housing density but noted minimum zoning restrictions of 0.81 and 1.62 houses/ ha. Kilpatrick & Spohr (2000b) found a housing density of 1.5 houses/ha within the annual home ranges compared to the study sites 1.7house/ha, but housing density within core ranges was only 0.12 houses/ha. Similarly, Storm et al. (2007b) found housing density to range between 0.13-0.18 dwellings/ha depending on utilization distribution and season. Compared to our study which detected an average of 71.3 residential properties in female core ranges and 129 properties in male core ranges. We calculated housing density within 50% core areas at 2.31 properties/ha during summer and 3.07 properties/ha during winter for combined sexes. The metropolitan zone of Howard County, which encompasses all five study sites has 2.01 residential buildings/ha. Howard County in total has a housing density of 1.12 residential buildings/ha. These results demonstrate the importance of deer encountering humans and human-used spaces which may increase spread of zoonotic disease and tick exposure in suburban areas. Potapov et al. (2014) found that deer avoided building densities greater than 6.0/ha, which was not available in our study area. They used areas with 4.0 buildings/ha or less often but preferred densities of 1.0 building/ha. However, these calculations were done with all buildings whereas ours was restricted to residential buildings to key in on suburban use and potential crossover of deer, ticks, and people. In our study, deer were often close to schools, park facility storage sheds, commercial businesses which would have increased our overall building density for both the study site calculations and within deer home ranges.

Movement

Massé & Côté (2013) found movement rates for female deer to be 58.1 m/h ± 0.5 during summer and 28.8 m/h ± 0.5 during winter which were slower than our reported female movement rates of 83.5 m/h ± 115.3 and 68.5 m/h ± 116.4 for summer and winter respectively. Average movement rates are slower in winter similar to Massé & Côté (2013). However, Massé & Côté (2013) used 2h sampling frequency compared to our 1h sampling frequency and longer sampling frequencies are known to underestimate step lengths because of the tortuous path an animal actually takes compared to Euclidean distance measured between consecutive points (Rowcliffe et al., 2012). Additionally, movement rates are significantly affected by period of day (Massé & Côté, 2013; Rhoads et al., 2010). Movement was greatest during dawn and dusk throughout the year and lowest during daylight hours in our study (Fig. 9). Tomberlin (2007) and Rhoads et al. (2010) reported similar diurnal trends for white-tailed deer in Maryland. Rhoads et al. (2010) found evidence that deer movement peaked during dusk hours but exhibited a slight secondary peak during dawn hours that was only evident during non-winter months. We found evidence for strong increases in movement at crepuscular periods throughout the year **(**Fig. 9**).** Although the morning/dawn movements are weaker than dusk movements, there is still an evident spike in movement rate at both dawn and dusk throughout the year (Fig. 9**)**.

Female average daily movement rate in this study were lowest at the end of May through beginning of June, corresponding to peak fawning season in this region (Dion et al., 2020; McGinnes & Downing, 1977; Fig. 10). Movements gradually increased from that point until peaking again late September and early October, then continued to decline throughout the hunting season. Archery season in MD usually beings the second week of September. Rhoads et al. (2010) noted home range size of exurban female deer to be the smallest during fawning season due to lack of mobility in fawns. Home range size did gradually increase until early hunting season and it was postulated that this happens because females gradually increase movement as fawns age throughout the year.

Variability in daily movement rates not explained by biological seasons such as parturition or rut could be explained by the spatial distribution of resources (Massé & Côté, 2013). Periods of low movement could be attributed to residence time or high site fidelity to a specific resource whereas periods of heightened movement may be searching for a new resource (Massé & Côté, 2013).

Maximum movement rates seem to be greater during daylight hours even though average movement rates are lowest during this period (Table 11). It is possible that overall movement rate is greater during crepuscular and night hours but a majority of long-distance movements occurred during the day. Further analysis would be needed to characterize the movements to see if they were within home range movements, excursions, or dispersals. Additionally, movement rates are slower in winter even though home ranges are relatively larger. Deer may be experience more sporadic movement during these months. Periods of increased movement searching for food and expanding range followed by periods of decreased movement once suitable forage and cover is found and remains level until the source is exploited (Massé & Côté, 2013).

Residential and Parks/Open Space movement rates were not statistically different for neither males nor females. Average movement rates were faster in residential areas. When comparing turning angles within residential developments and more natural areas there was not significant difference, but there was small shift towards straighter or more persistent movement through residential areas (Fig. 11).

Similar to movement rates, deer average distance to residential buildings has diel and seasonal patterns (Figs. 12 & 13). Deer are often further away from homes during the day and closer at night. There is also a seasonal trend for each sex. Overall, females are consistently located closer to homes than males, and females are furthest away during March - May which may be caused from females searching for adequate birthing cover or embarking on spring dispersals. Female distance to buildings gradually decreases throughout the year until the next spring. Males are generally furthest away from residential buildings during November and again in early spring which coincides with rut and spring dispersal events.

Increased use of residential areas during winter months combined with prolonged tick activity and lessened tick mortality may increase or intensify chances of homeowners becoming exposed to tick borne disease and ticks bites.

CONCLUSIONS

White-tailed deer will use residential land, and it is often a sizeable proportion of their corresponding home ranges. Deer still exhibit slight avoidance behaviors or strategic use of these areas based on greater movement rates within residential land in straighter direction compared to natural areas which could correspond to use of suburbs as movement corridors or foraging patches. Average GPS distances to residential buildings were furthest during sensitive times of the year (e.g. parturition or rut) showing deer avoid these areas at particular times of the year.

Greater movement rates and straighter movement paths can be interpreted as strategic feeding throughout residential areas, using residential areas as corridors for movement between resources, or general fear or avoidance and wanting to spend less time in these areas. However, these differences in movement rate and turn angle were either weak or not significant, which could be evidence showing that deer are familiar with residential areas as much as natural areas. Individual personality and fear may play a large role in determining intensity of use in residential areas for white-tailed deer population. More research is needed to elucidate personality or individuality and that influence on space use and behavior in urban areas.

Female deer are more tolerant of residential land use than male deer. Female GPS distances are consistently closer to residential developments and there was relatively small difference in movement rate or angle between residential and natural areas, signaling no change in behavior between the two areas. Males are consistently found further from residential development and exhibited a stronger change between residential land and park areas showing greater increase in movement rate and straighter path of direction in residential areas. When considering white-tailed deer's ability to transport and maintain tick populations, female deer may pose more risk than male deer to increase chances of exposure to ticks and tick-borne disease because of their propensity and relative level of comfort inhabiting residential areas. Research has shown that a majority of tick bites/encounters originate on personal properties within their own backyard (Stafford et al., 2017), and female deer are more likely to transport and support ticks close to residential properties.

Chapter 4: Conclusion

White-tailed deer (*Odocoileus virginianus*) are a regular occurrence in suburban neighborhoods. Deer can acclimate to residential human activity and exploit benefits of increased forage availability, fewer predators and little to no hunting. However, this creates deer-human conflict, particularly exposure to zoonotic disease and other pathogens among humans, livestock, and pets. New developments sprawling outwards from urban centers will further drive the need for related management to provide solutions. Additionally, climate change may have profound impacts to host-parasite ecology exacerbating risk in areas with established presence of tick-borne disease. Prolonged warming seasons may consequently prolong active tick seasons and increase risk of ticks finding a bloodmeal throughout the year.

Disease management for white-tailed deer will need a focus on active vector surveillance and monitoring. Trapping white tailed deer in suburban areas can be a great compliment to hunter harvested deer, and in some cases a more accurate account of certain parasite loads. Additionally, firearms and hunting restrictions can often eliminate hunting as a management tool, but trapping can be used even when building densities are high. Deer have been reported regularly using areas with building densities ranging from 1-4 buildings/ha, and as shown in this study, highly fragmented areas can prove to be productive trapping locations. Trapping can be useful in special circumstances to control certain parts of the population, monitor parasite and pathogen loads, and treat or vaccinate individuals from disease. Trapping white-tailed deer in smaller urbanized parks was more efficient in our study. Cold weather and snow likely increased trapping success as well as the presence of recreational sports fields. Trapping can also be used as a method for sample collection during periods of peak tick activity outside of deer hunting seasons. Drop netting is a proven method to capture groups of deer but box traps make a good addition to a trapping program. Taking proactive measures to monitor disease will make managers more prepared to develop necessary containment and eradication plans.

Deer regularly use suburban neighborhoods. Different patterns in movement and space use of residential land between time and sex can have important implications for humans' risk of exposure to disease. When considering white-tailed deer's ability to transport and maintain tick populations, female deer pose more risk than male deer to increase chances of exposure to ticks and tick-borne disease because of their propensity to inhabit residential areas. Research has shown that a majority of tick bites originate on personal properties in yards during everyday activities (Stafford et al., 2017). Female deer are more likely to transport and support ticks closer to residential properties. It is important to note that because males often have larger ranges, they come in contact with a greater number of residential properties overall, but they also move faster than females through residential neighborhoods reducing time spent in these areas. Summer and Fall seasons are particularly sensitive times of year concerning exposure to ticks due to peak tick activity, however winter is also a sensitive period because deer use of residential land can intensify and ticks remain active on climatically favorable days. Reducing the time deer spend in residential areas could possibly reduce risk of exposure to ticks and other diseases. Residents can use fencing and other deterrent methods to discourage deer movement in their properties. Additionally, maintaining a host-targeted treatment for tick control throughout winter is recommended.

Howard County, like many other suburban areas, are managing over abundant deer populations in effort to reduce deer-human conflict. Documented complaints and opinions from local residents heightened the priority of correcting these issues (Norris, 2008). Lethal management and reducing densities of deer is a straightforward tactic for management campaigns aiming to reduce deer-auto collisions, browsing damage to forests, crops, and ornamental plantings. However, the complex relationship between deer and incidence of tick-borne disease will require an integrated management approach to reduce tick abundances and its correlated incidence of human disease. Reducing deer densities will help reduce tick host densities and ability of ticks to reproduce, but with diminishing returns because of ticks' ability to host-switch to more abundant hosts (Williams et al., 2018). Furthermore, disease abundance and transmission dynamics depend on reservoir competence. Deer have long been linked to Lyme disease, but recent research has targeted *Peromyscus spp*. as better reservoirs for *Borrelia*, the causative agent of Lyme disease. Indicating that deer may have a little influence on the direct transmission of in *Borrelia* in the environment. However, deer are competent reservoirs for other tick-borne pathogens such as *Anaplasma phagocytophilum*, which can facilitate *Borrelia* replication (Nieto & Foley, 2009). Therefore, any disease management protocol must consider or account for deer ecology and influence in disease transmission. Regardless, transmission of disease at first requires contact between vector and host. Reducing densities of deer will aide in slowing transmission and spread of disease but will unlikely have much effect on eradication of disease without accounting for multiple host and vector ecologies. Policies that increase deer harvest in urban areas and encourage harvest on females will aide to reduce human-deer conflict and the number of deer in neighborhoods. Localized management of specific matrilineal groups is a recommended objective for managed hunting or sharpshooting (Crawford et al., 2018). Reducing archery safe zone restrictions and promoting urban archery programs can provide more opportunities for hunting to help reduce population densities.

Future Considerations

More research is needed to better understand fine-scale habitat use of white-tailed deer in a highly fragmented landscapes, especially to identify bedding areas. Increasing advances in remote sensing technologies, such as LiDAR and drones, may provide new detail of habitat mapping which can capture understory vegetation composition or densities. Combining robust, fine-scale movement models and deer activity data could provide data on deer behavior in the suburban landscape. Bedding cover for deer often involves thick, brushy cover which can increase chances of deer encountering ticks. Deer exhibit high site fidelity to known places of forage and cover. The chances of ticks dropping off deer in bedding cover could greatly increase due to the time spent in a single area. Identifying areas of preferred bedding habitat directly adjacent to backyard properties may be specific high-risk areas for encountering ticks. Further research could identify if there are higher abundances of ticks in areas identified as bedding cover compared to other locations on the landscape. Research is needed to understand how fencing type and design can restrict deer access to private properties, and if this has implications for time spent in the area by deer or the abundance of ticks. Tick distribution on the landscape is heavily influenced by host movement. There is ample research documenting tick seasonal activity and peak feeding times. More research is needed to understand tick ecology while on the host with a particular focus towards time spent on the host. There is a lack of knowledge how long ticks will remain attached to hosts for purposes of breeding and feeding. Seasonal trends in attached tick behavior can have implications for how they are spread through the environment by long-ranging hosts.

Often many management campaigns are unsuccessful due to cost or inability to target and treat a majority of the population. Successful management will require strong collaborations and an integrated approach to reduce human-deer related conflict. Now more than ever, widespread community awareness and engagement in local management activities is needed for success. Building partnerships and trust between private landowners and natural resource agencies can provide support for management activities and access to a greater proportion of the population enabling more successful management.

Tables

Table 1. Summary of the five county parks used as deer trapping sites in Howard County, Maryland.

Trapping Site	Size (ha)	Amenities	Density deer/km²		Population Management
			2017	2018	
Cedar Lane Park	37.6	Athletic fields, storage facility, picnic area, paved trails, playgrounds	N/A	N/A	None
Middle Patuxent Environmental Area	418	Unpaved trails	41	21	Managed hunting
Wincopin Trails/Savage Park[a]	143	Paved/unpaved trails, athletic fields	12.5[b]	N/A	Managed hunting & sharpshooting
Rockburn Branch Park	168	Disc golf course, athletic fields. storage facilities, play grounds	17	61.9	Sharpshooting
Blandair Regional Park	60.7	Historic farm estate, unpaved trails	N/A	174	Managed hunting & sharpshooting

[a]Wincopin Trails and Savage Park are directly adjacent recreational areas.
[b]Deer density was only calculated for Savage Park in 2017 not Wincopin Trails

Table 2. Mean ± SD and median location error (LE) in meters for eight test sites used during collar calibration. "Developed" cover refers to test sites where sky availability was obstructed from houses, buildings, and urban structures whereas "Natural" cover refers to test sites where sky availability was obstructed by vegetation and tree canopies.

Site	Cover	Canopy Cover %	Mean LE ± SD	Median LE
1	Natural	100	5.09 ± 5.6	3.73
2	Natural	75	6.60 ± 7.0	4.97
3	Natural	100	7.87 ± 11	4.85
4	Developed	75	8.14 ± 6.2	6.50
5	Natural	45	10.1 ± 15	7.50
6	Natural	15	11.7 ± 11	8.77
7	Developed	65	12.1 ± 16	7.33
8	Natural	15	14.8 ± 12	11.6

Table 3. White-tailed deer captures, trap events, and capture success at five county parks in Howard County, Maryland 2017-2018.

Trapping Sites	Year	Total Captures	Trap Events	Successful Trap Events	Overall Capture Success %	Deer/Trap Event
Cedar Lane	2017	26	24	10	46.2	0.92
	2018	3	2	2		
MPEA*	2017	12	26	9	28.2	0.38
	2018	5	13	2		
Wincopin Trails/Savage Park	2017	21	28	12	35.3	0.57
	2018	8	23	6		
Blandair Regional Park	2017	N/A	N/A	N/A	40	1
	2018	20	20	8		
Rockburn Branch Park	2017	N/A	N/A	N/A	40.6	0.94
	2018	30	32	13		
Total		118	168	62	36.9	0.7

*Middle Patuxent Environmental Area

Table 4. Counts of life stage and species for ticks collected from live-captured deer in Howard County, Maryland 2017-2018.

Life Stage	*Ixodes scapularis*	*Amblyomma americanum*	Total	Percent
Male	6	49	55	37
Female	10	34	44	29.5
Nymph	2	48	50	33.5
Total	18	131	149	
Percent	12	88		100

Table 5. Summary from GIS analysis of buffered areas around five deer trapping sites. Total area reported as well as percent land cover classifications. Distance, density, or percent area of county features are also included for the study sites in Howard County, Maryland. *Patch Density*, *Landscape Division Index*, *Forest Edge Density* were calculated in Fragstats software.

Trapping Site	**Cedar Lane**	**Rockburn Branch**	**Blandair Regional**	**Wincopin Trails/Savage**	**Middle Patuxent Environmental Area**
Total Buffer Area (ha)	408.00	314.00	314.00	314.00	487.00
Capture Success (%)	46.20	40.60	40.00	35.30	28.20
Urban Cover (%)	52.70	45.10	52.80	37.90	27.40
Forest Cover (%)	27.97	34.39	35.79	57.76	67.69
Grass Cover (%)	19.31	20.38	11.18	3.20	4.81
Building Cover (%)	7.39	5.19	5.67	3.77	3.90
Euclidean Distance to buildings (m)	82.10	100.90	100.20	138.40	158.50
Recreational Field Cover (%)	3.62	0.99	0.94	1.21	1.31
Euclidean Distance to Recreational Fields (m)	277.40	298.20	483.40	604.63	684.30
Road Density	0.011	0.0073	0.014	0.0083	0.0060
Euclidean Distance to roads (m)	67.56	60.62	76.03	92.60	159.79
Stream Density	0.0023	0.0031	0.0023	0.0023	0.0041
Patch Density	31.50	20.25	25.63	9.42	3.03
Landscape Division Index	0.48	0.48	0.49	0.43	0.03
Forest Edge Density	387.93	273.96	376.03	155.53	110.51

Table 6. Model selection results of the top five general linear models evaluating capture success of white-tailed deer in Howard County, Maryland, 2017-2018. Model summaries are available in Appendix A.

	Model	***K*[a]**	**AIC**	**ΔAIC[b]**	**w_i[c]**
1	*Temp*[d]	1	225.41	0.00	0.428
2	*SF*[e]*+Temp*	2	226.13	0.72	0.298
3	*SD*[f]*+SF+Temp*	3	226.85	1.44	0.208
4	*PRCP*[g]*+SD+SF+Temp*	4	229.50	4.09	0.055
5	*Sport*[h]*+PRCP+SD+SF+Temp*	5	233.18	7.77	0.009

[a]number of model parameters; [b]ΔAIC=relative difference to best performing model; [c]AIC weight; [d]daily min. temp, °C; [e]daily snowfall, cm; [f]daily snow depth, cm; [g]daily precipitation, cm, [h]% recreational field cover

Table 7. Autocorrelated kernel density home range estimates (hectares), SD, and range of 95% and 50% contour sizes for female and male white-tailed deer in Howard County, Maryland 2017-2019.

		95% contour			**50% contour**			
Sex	**Season**	**Mean**	**sd**	**Range**	**Mean**	**sd**	**Range**	**n**
Female	Annual	106	96.2	21.7 - 315	20	17.2	3.71 – 53.3	10
Female	Summer	43.4	39.2	7.09 - 173	9.97	10.6	1.40 – 47.2	21
Female	Winter	89.1	53.0	27.4 - 154	18.1	9.98	5.74 – 27.9	8
Male	Annual	317	184	60.7 - 473	43	31.1	8.08 – 83.7	4
Male	Summer	137	111	18.7 - 338	27.6	25.9	1.95 – 67.7	11
Male	Winter	347	226	75.6 - 717	68.5	35.3	12.4 - 106	6

Table 8. Wilcoxon Rank Sum test of annual home range sizes, seasonal home range sizes, and proportion of residential properties by home range contours and sex.

Wilcoxon Rank Sum Test	**Sex**	**Home Range Contour Level**	**W**	**p-value**
Annual range size	Male/Female	95	7	0.076
		50	8	0.11
Summer - Winter size	Female	95	85	0.0134
		50	81	0.00928
Summer - Winter size	Male	95	19	0.03281
		50	16	0.01699
Summer – Winter proportion of res. land	Female	95	63	0.3242
		50	74	0.64
	Male	95	22	0.3

Summer - Winter proportion of res. land	50	15	0.08

Table 9. Mean, SD, and range of residential properties within 50% home range contours for male and female white-tailed deer in Howard County, Maryland 2017-2019.

Sex	Season	Mean	sd	Range	n Deer
Female	Annual	71.3	85.3	3 - 244	10
Female	Summer	35.3	74.8	0 - 350	21
Female	Winter	63	61.1	6 - 194	8
Male	Annual	128	159	5 - 350	4
Male	Summer	89.2	123	0 - 303	11
Male	Winter	212	213	15 - 570	6

Table 10. Kruskal-Wallis Rank Sum tests of movement rates by time of day and corresponding Dunn's post hoc test.

KW rank sum test	Sex	KW chi-squared	df	p-value
Time of Day	female	16.771	2	.00023
Time of Day	male	12.39	2	.0020
Dunn's post hoc test	**Sex**	**z**	**p-value**	
crepuscular - day	female	4.017378	.00018	
crepuscular - night	female	34.9778	.014	
day - night	female	-26.3178	.187	
crepuscular - day	male	3.506804	.0014	
crepuscular - night	male	2.014959	.088	
day - night	male	-1.491845	.136	

Table 11. Mean, SD, and maximum movement rates (meters/hour) by season and time of day for male and female white-tailed deer in Howard County, Maryland 2017-2019.

Sex	Season	Time of Day	Mean	sd	Max	n
Female	Annual	Crepuscular	127	152	2476	15
		Day	75.5	117	3171	
		Night	88.4	129	2248	
	Summer	Crepuscular	110	138	2476	11
		Day	83.5	115	2132	
		Night	83.7	114	1342	
	Winter	Crepuscular	141	160	1553	8
		Day	68.5	116	2361	
		Night	87.8	128	2248	
Male	Annual	Crepuscular	134	183	2151	12
		Day	78.5	143	6048	
		Night	108	180	2472	
	Summer	Crepuscular	117	165	1403	11
		Day	66.2	110	2039	
		Night	76.6	121	1995	
	Winter	Crepuscular	158	191	1599	8
		Day	80.3	176	6048	
		Night	117	181	1810	

Table 12. Mean, SD, and maximum distances to residential buildings (meters) by season and time of day for male and female white-tailed deer in Howard County, Maryland 2017-2019.

Sex	Season	Time of Day	Mean	sd	Max	n
Female	Annual	Crepuscular	88.7	93.1	3283	33
		Day	88.8	91.3	3805	
		Night	79.5	92.7	3290	
	Summer	Crepuscular	76.3	75.3	457.1	27
		Day	76.7	70.5	497.4	
		Night	73.4	77.3	441.2	
	Winter	Crepuscular	79.3	79.7	574.9	21
		Day	75.8	65.8	532.2	
		Night	65.8	78.4	524.8	
Male	Annual	Crepuscular	117	122	1527	18
		Day	126	119	1929	
		Night	114	136	2355	
	Summer	Crepuscular	103	103	577.9	16
		Day	109	97.8	954.5	
		Night	107	104	652.3	
	Winter	Crepuscular	119	107	491.3	14
		Day	137	102	503	
		Night	104	110	495.7	

Figures

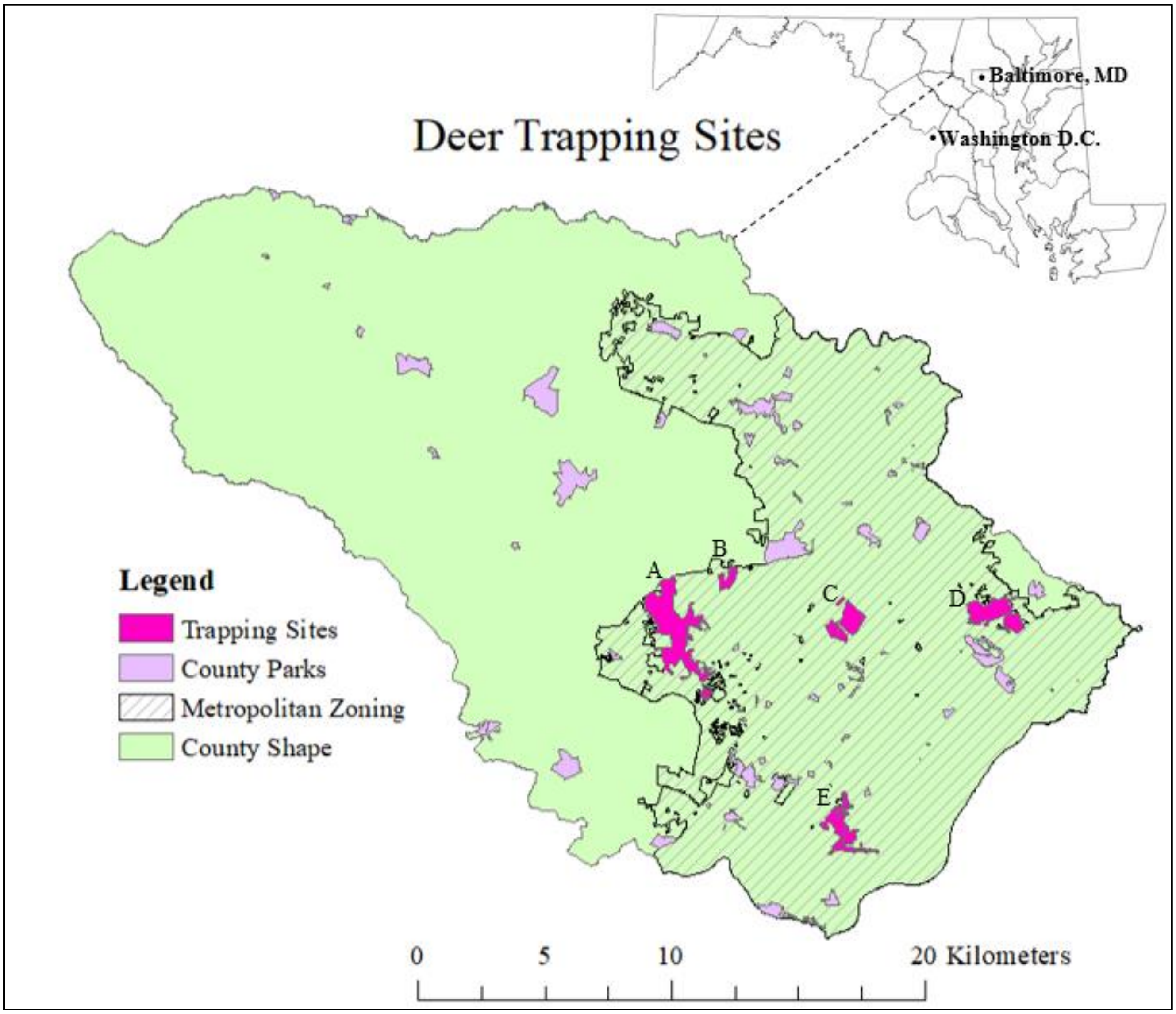

Figure 1. Map of Howard County, Maryland and metropolitan zone containing the five county parks selected for deer trapping. Other county parks are depicted as purple polygons. Individual trapping sites are labeled as A: Middle Patuxent Environmental Area, B: Cedar Lane Park, C: Blandair Regional Park, D: Rockburn Branch Park, and E: Wincopin Trails System/Savage Park.

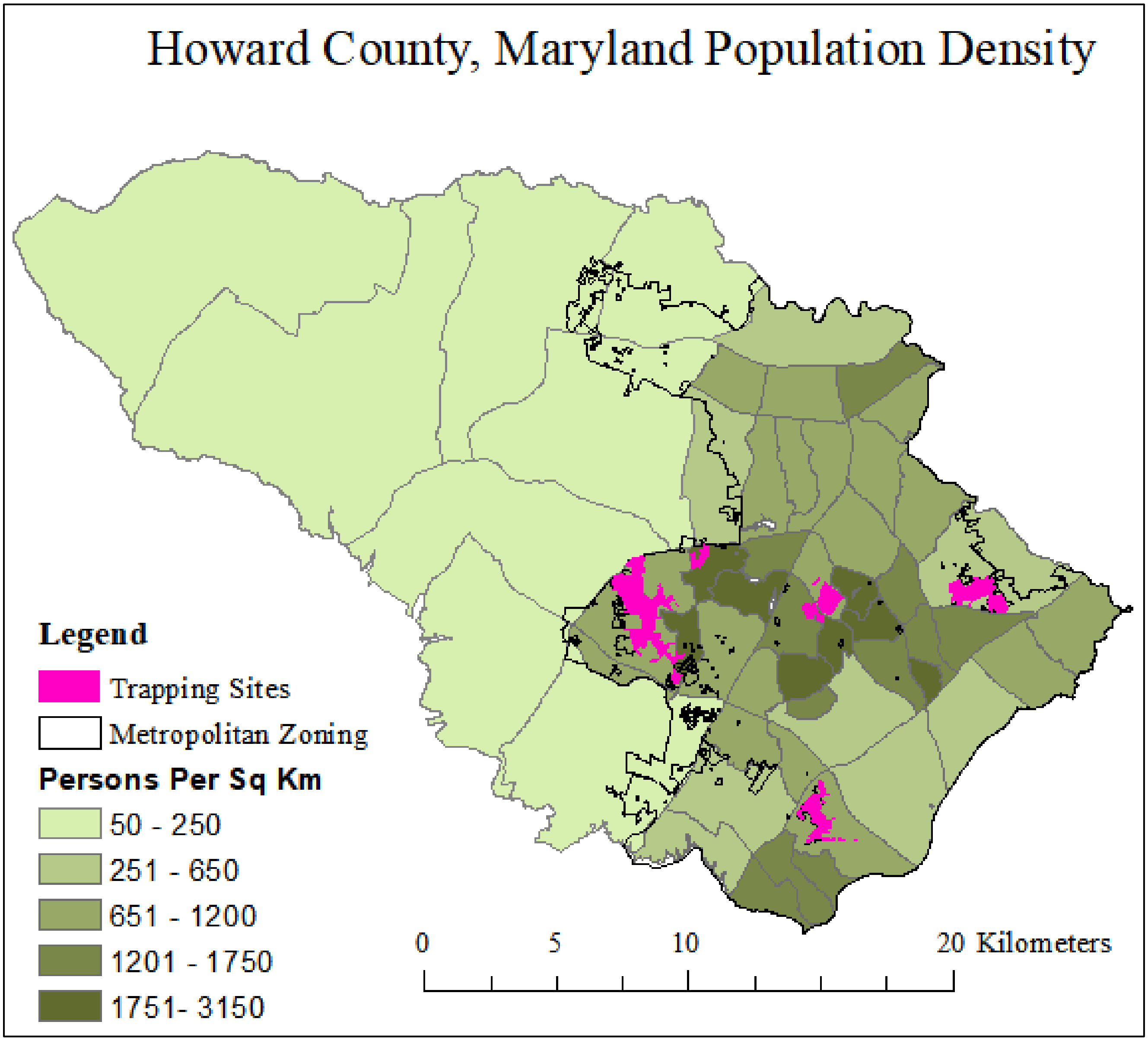

Figure 2. Map of Howard County, Maryland population density by census tract in persons per square kilometer 2017. All five trapping sites are within the metropolitan zone characterized by greater population densities.

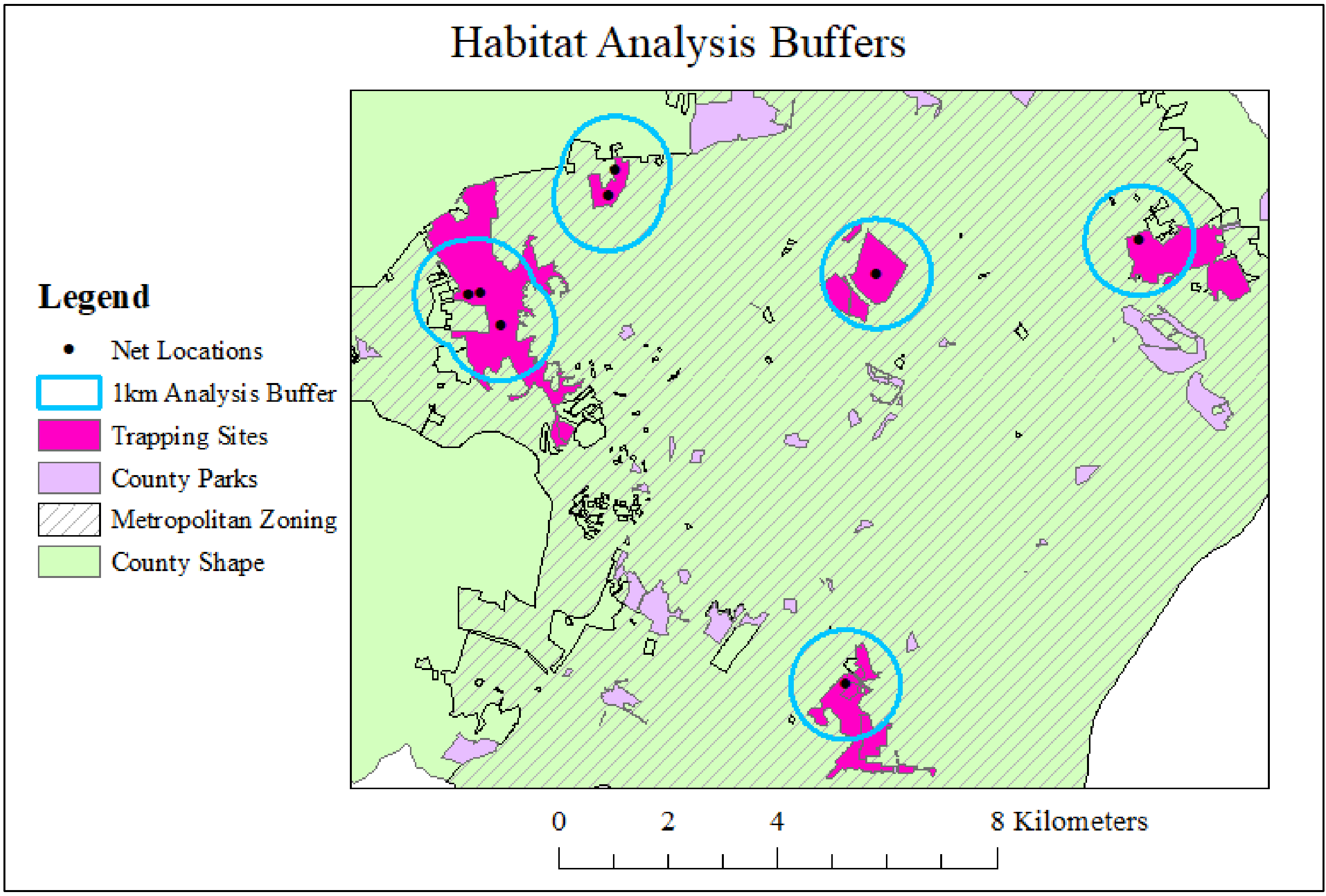

Figure 3. Map of five selected parks and specific drop net locations in Howard County, Maryland that have 1000 meter buffer zone radius surrounding trapping sites. Buffers that overlapped were merged as one.

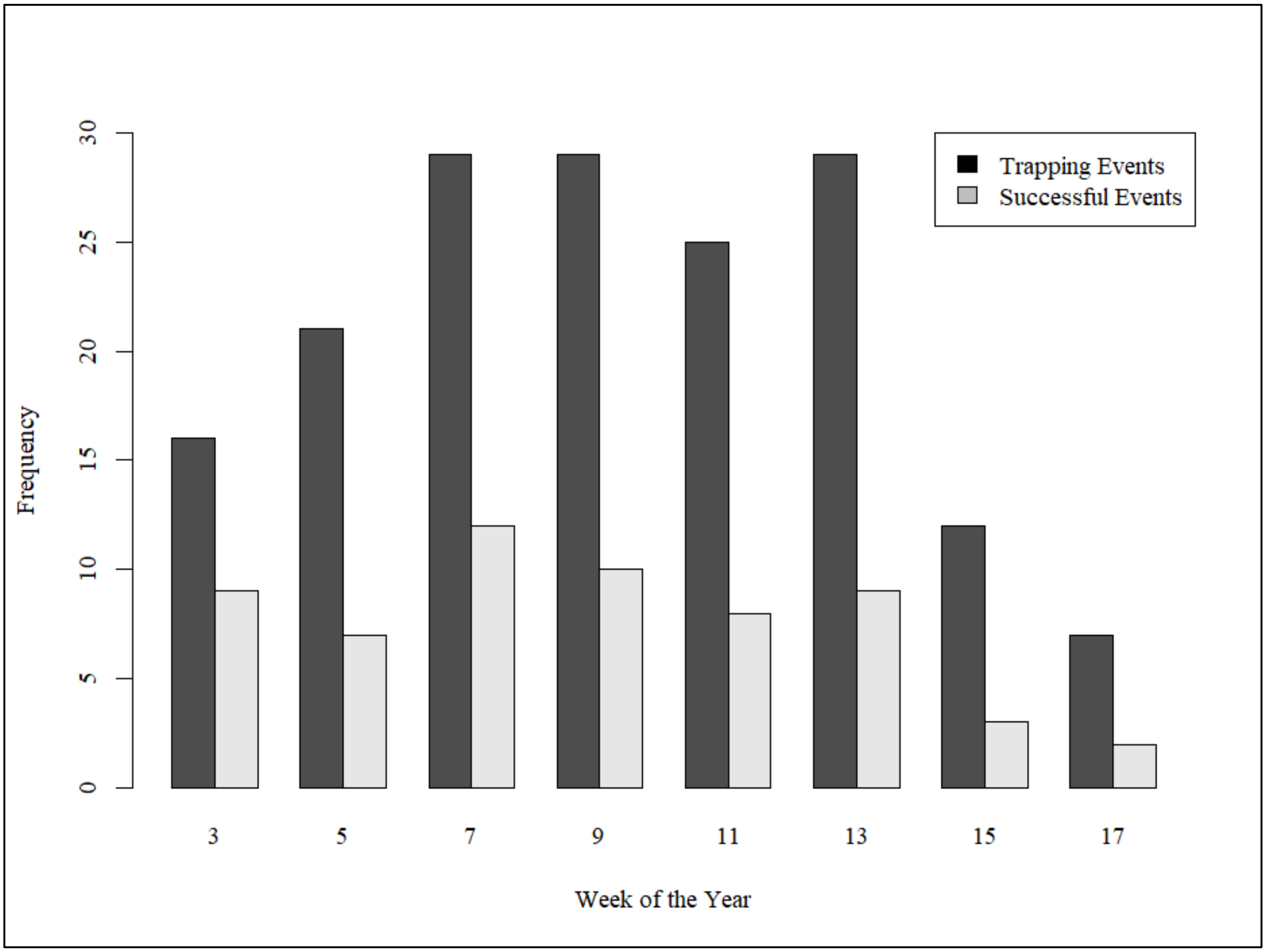

Figure 4. Histogram showing frequency of trapping effort per week from beginning of the trapping season next to successful trapping events by week across all parks and combined years for white-tailed deer captures in Howard County, Maryland 2017-2018.

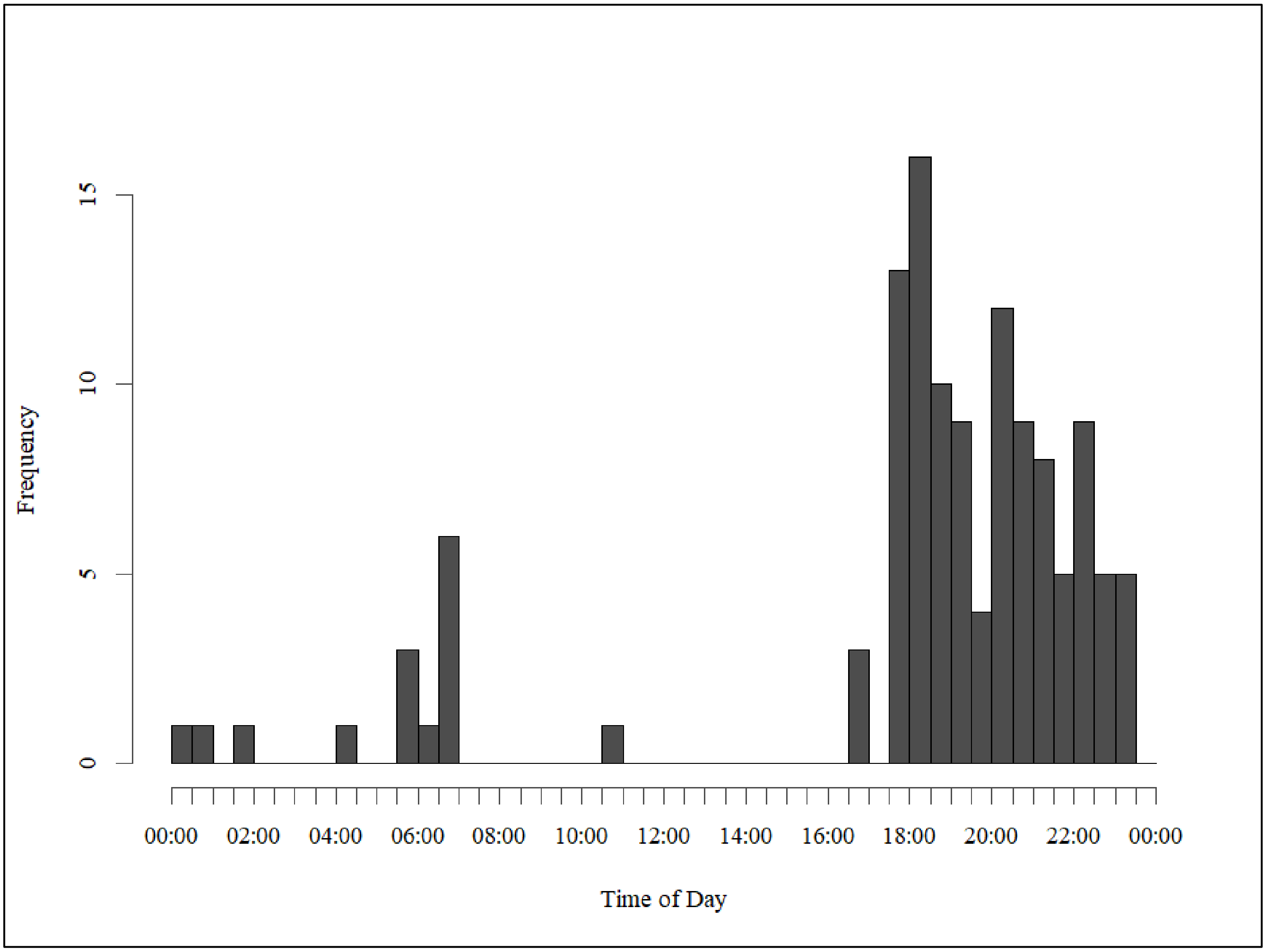

Figure 5. Histogram showing frequency of times of successful trap events across all trapping sites and combined years for white-tailed deer captures in Howard County, Maryland 2017-2018.

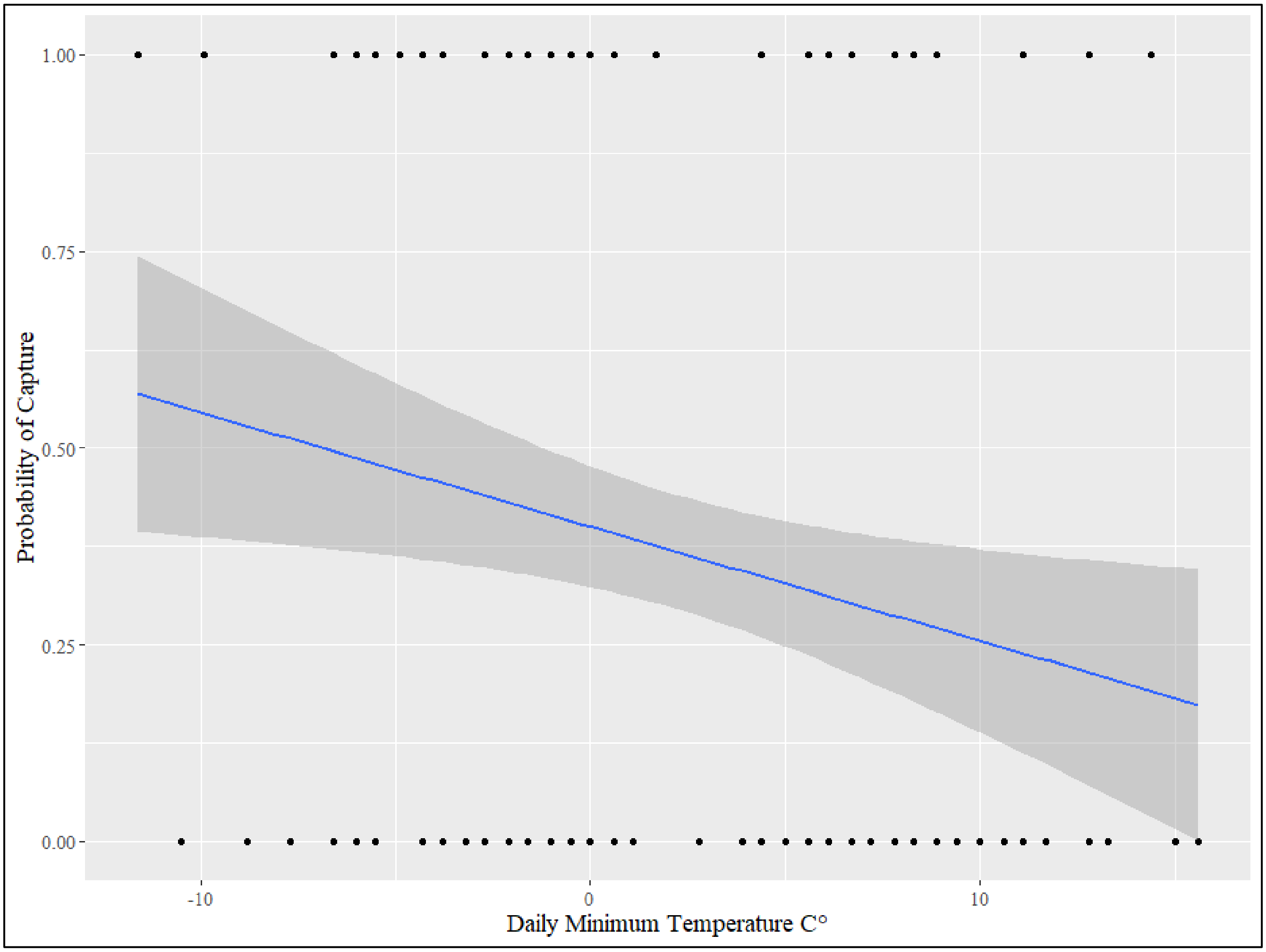

Figure 6. Regression of capture success vs. daily minimum temperature (°C) for white-tailed deer captures in Howard County, Maryland 2017-2018. (95% CI [-0.119, -0.013], RMSE= 1.13, p= 0.016).

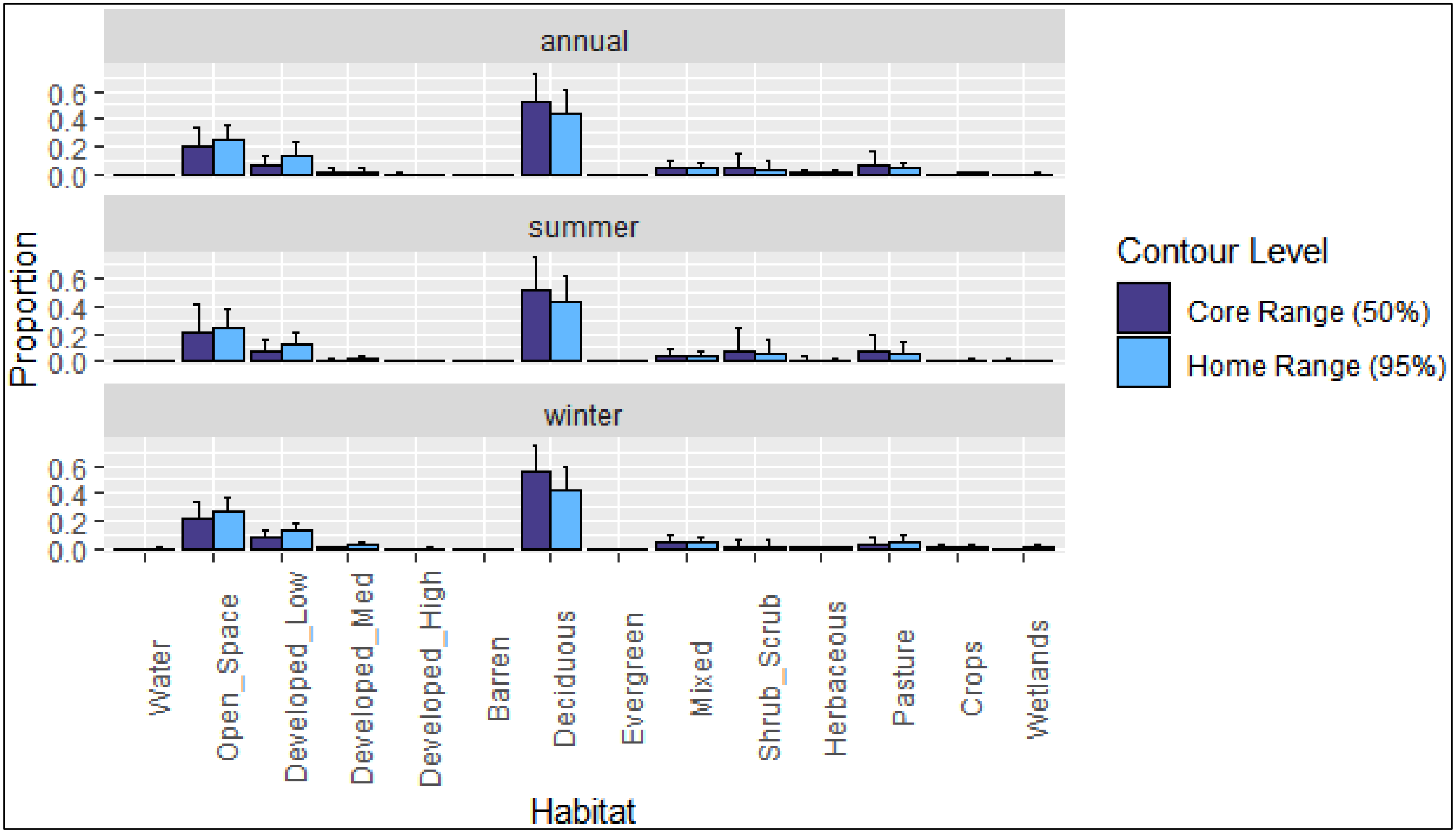

Figure 7. Proportion of habitat cover within white-tailed deer home range 95% and 50% contours for different seasons and combined sexes in Howard County, Maryland 2017-2019. Habitat cover classes are sourced from National Land Cover Dataset (NLCD 2016).

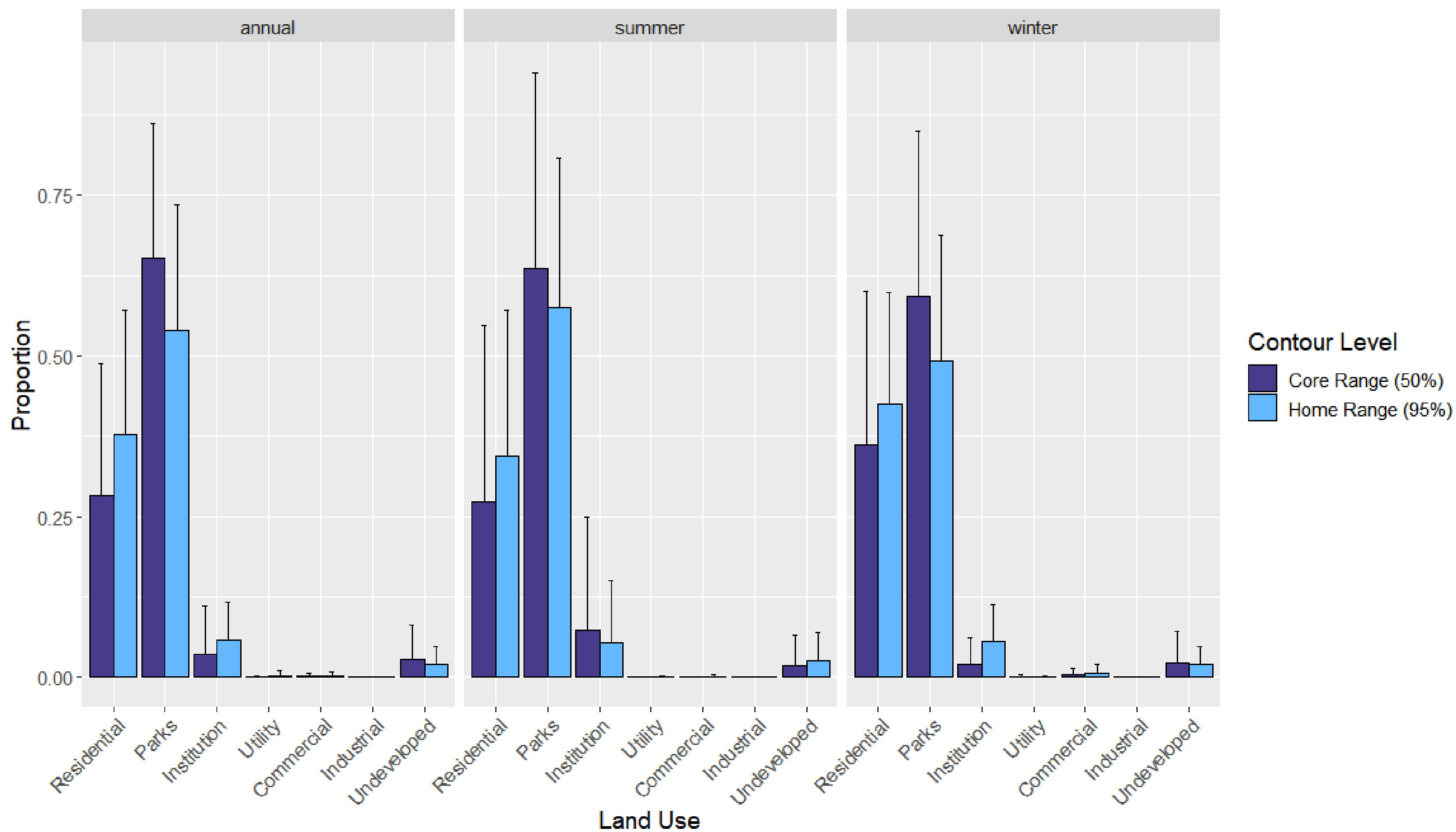

Figure 8. Proportion of land use cover within white-tailed deer home range 95% and 50% contours for different seasons and combined sexes in Howard County, Maryland 2017-2019. Land use cover classes are sourced from Howard County GIS and reclassified in Chapter 3.

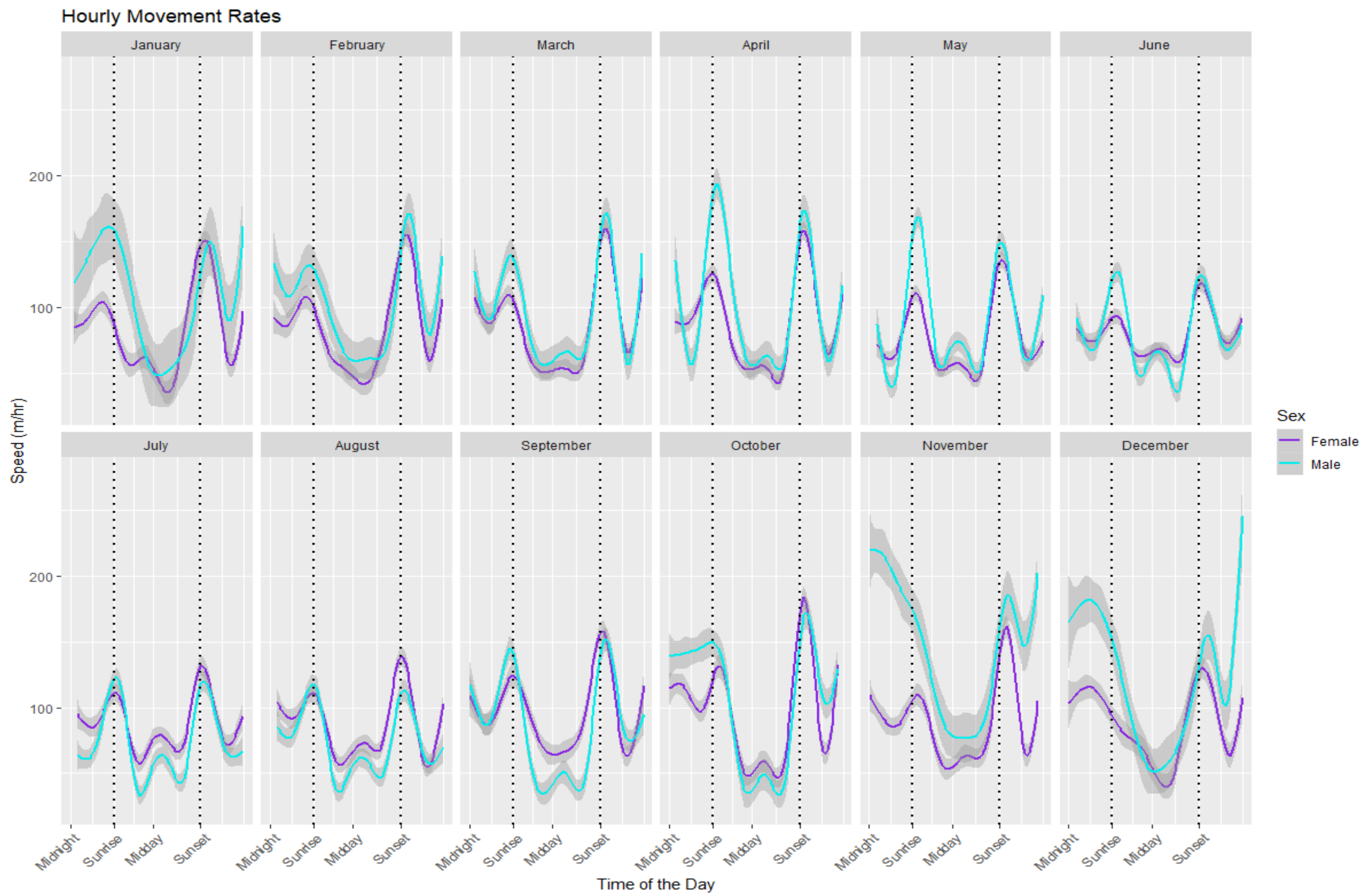

Figure 9. Diel trends in movement rates (meters/hour) for male and female white-tailed deer for each month the year in Howard County, Maryland 2017-2019. Dashed vertical lines correspond to sunrise and sunset.

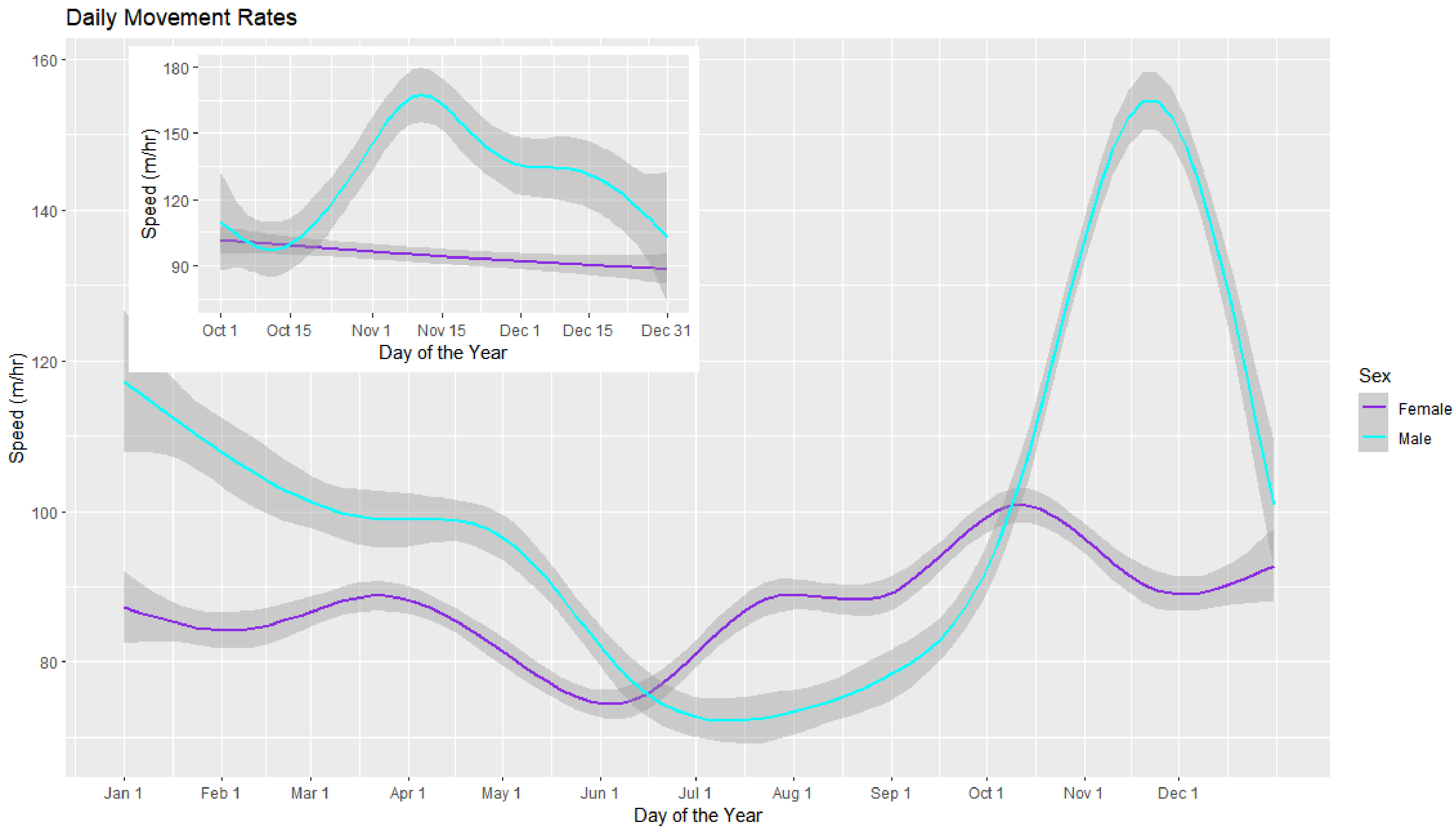

Figure 10. Daily trends in movement rates (meters/hour) for male and female white-tailed deer throughout the year in Howard County, Maryland 2017-2019. Inset graph is a closer look at movement rates from October-December.

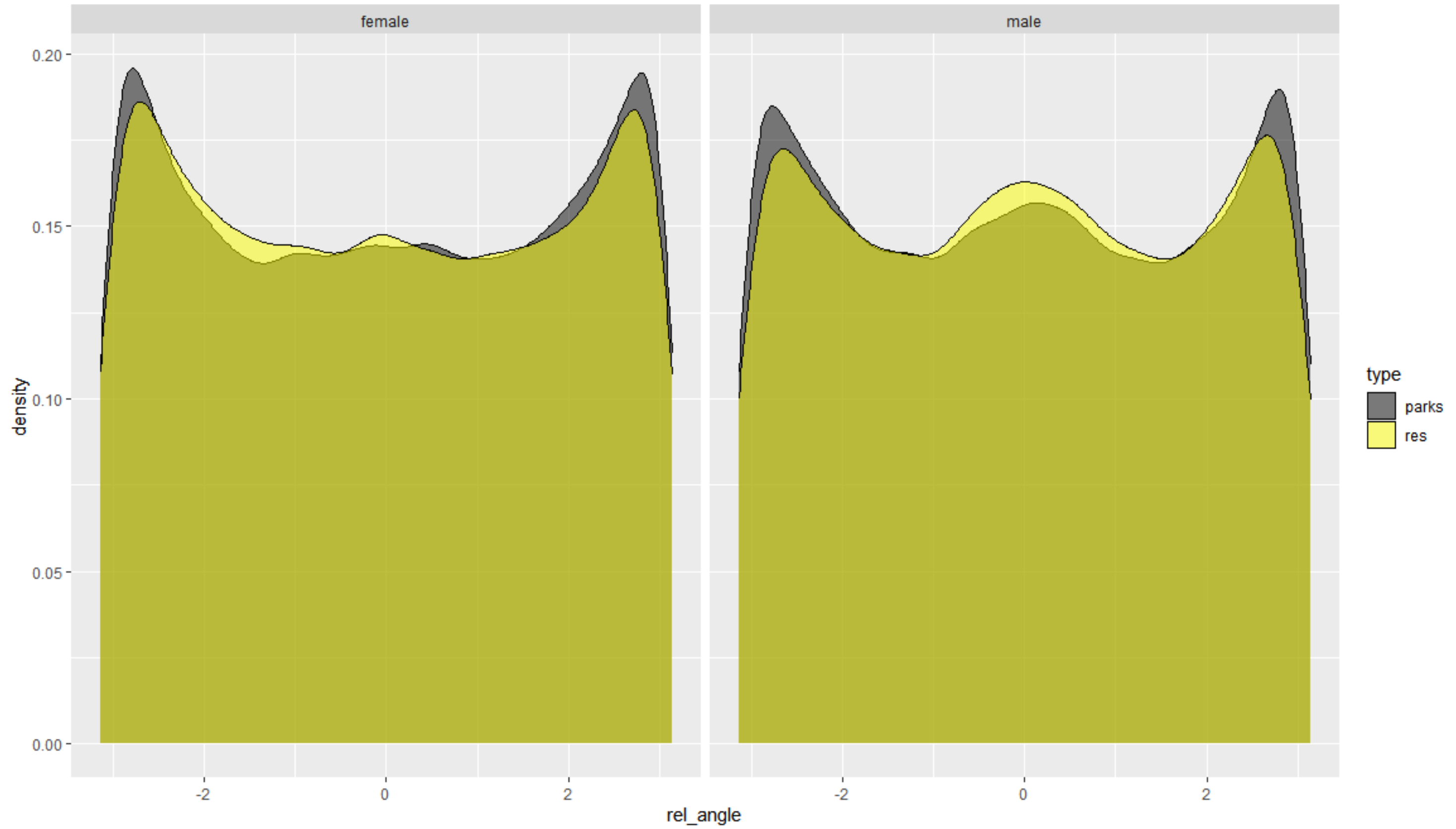

Figure 11. Density plot of relative turn angles (rel_angle) for female and male white-tailed deer. Black/grey layer designates movements within Park/Open Space whereas yellow designates movements within Residential land. “0” corresponds to no change in turn angle relative to previous step or straight-line movement. “-2/2” resembles sharp turning angles and a more tortuous movement path.

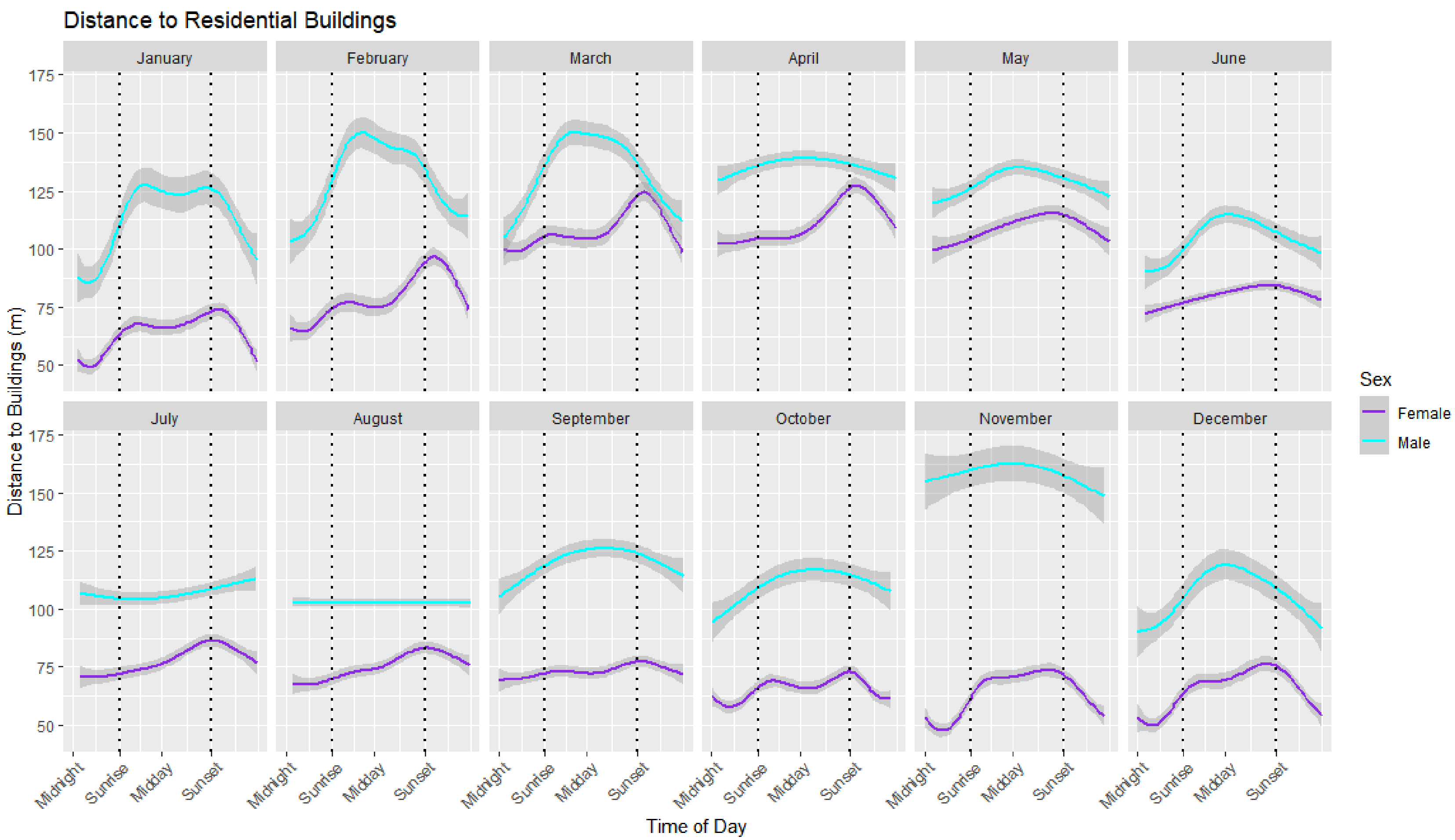

Figure 12. Diel trends in distance to residential buildings (meters) for male and female white-tailed deer for each month of the year in Howard County, Maryland 2017-2019. Dashed vertical lines correspond to sunrise and sunset.

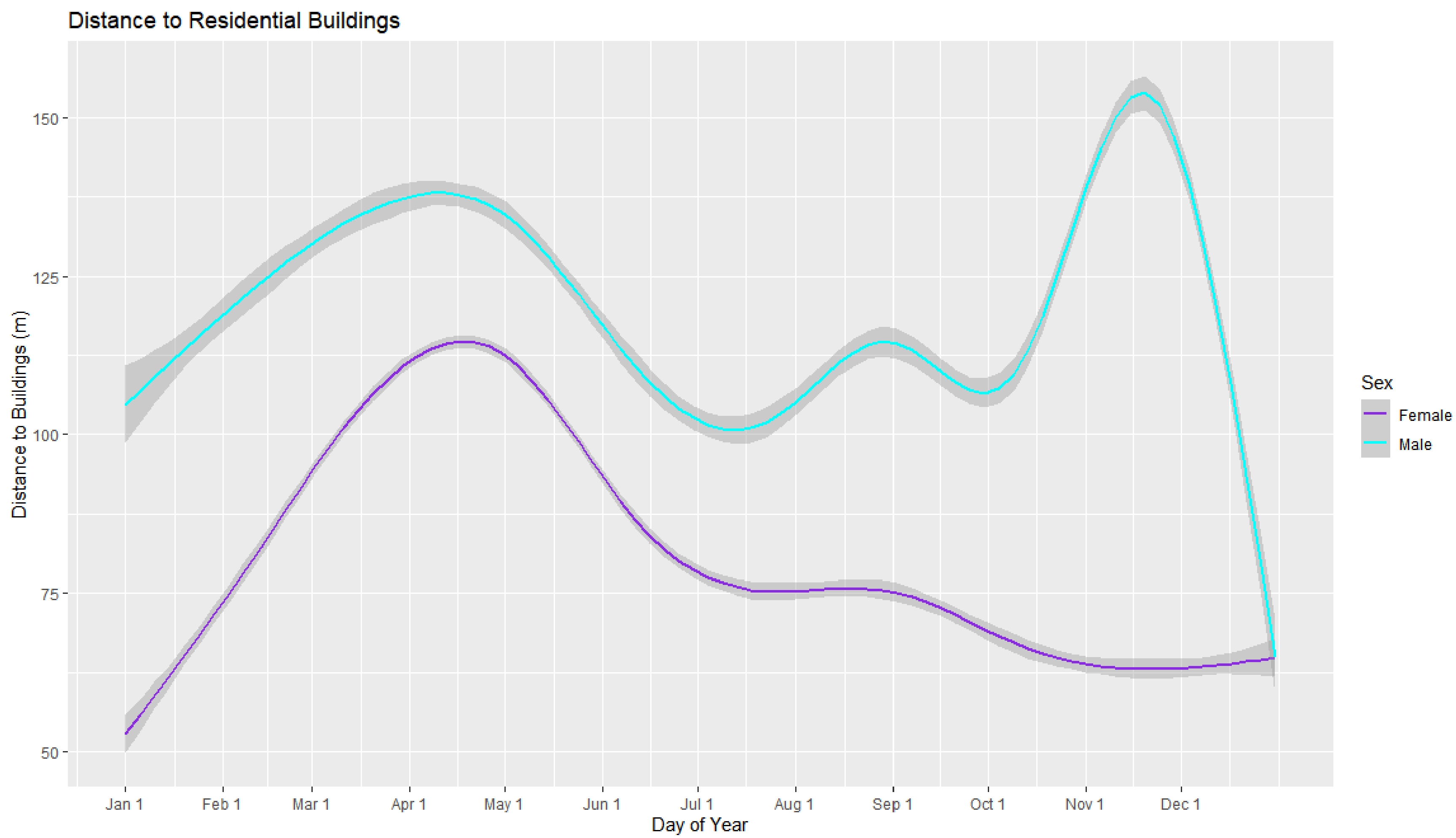

Figure 13. Daily trends in distances to residential buildings (meters) for male and female white-tailed deer throughout the year in Howard County, Maryland 2017-2019.

Appendices

Appendix A

Coefficients and summaries from top five performing models evaluating capture success of white-tailed deer in Howard County, Maryland, 2017-2018

		Model 1		
Variable	**Estimate**	**Std. Error**	**z value**	**P-value**
Intercept	-0.41913	0.16756	-2.501	0.0124
TMIN	-0.06464	0.02685	-2.408	0.0161
		Model 2		
Variable	**Estimate**	**Std. Error**	**z value**	**P-value**
Intercept	-0.35277	0.17111	-2.062	0.03924
SNOW	-0.08366	0.08129	-1.029	0.30342
TMIN	-0.07195	0.02731	-2.634	0.00843
		Model 3		
Variable	**Estimate**	**Std. Error**	**z value**	**P-value**
Intercept	-0.42703	0.17604	-2.426	0.0153
SNOW	-0.13648	0.12736	-1.072	0.2839
SNWD	0.03912	0.02782	1.406	0.1596
TMIN	-0.06476	0.0277	-2.338	0.0194
		Model 4		
Variable	**Estimate**	**Std. Error**	**z value**	**P-value**
Intercept	-0.35477	0.18223	-1.947	0.0516
PRCP	-0.08507	0.06715	-1.267	0.2052
SNOW	-0.11345	0.11151	-1.017	0.309
SNWD	0.04096	0.02934	1.396	0.1627
TMIN	-0.05601	0.02815	-1.99	0.0466
		Model 5		
Variable	**Estimate**	**Std. Error**	**z value**	**P-value**
Intercept	-0.68425	0.33014	-2.073	0.0382
sport	0.21971	0.18222	1.206	0.2279
PRCP	-0.08529	0.06872	-1.241	0.2145
SNOW	-0.10919	0.10603	-1.03	0.3031
SNWD	0.04053	0.02949	1.375	0.1692
TMIN	-0.06006	0.02847	-2.109	0.0349

Appendix B

List of supplies used in the deer trapping protocol. Includes examples and grouping.

Item	Purpose	Example	Grouping[1]
Emergency and Medical History Information	For emergency purposes: Relevant information for each crew member as well as information on immobilization and reversal agents used.	Formulation of immobilizing drugs, emergency numbers, hospital locations	All
Extra Batteries	Extra set of batteries for all devices in the field	Varies	All
Headlamp	Visibility at night	Varies	All
Ratchets, wrenches, screw drivers	Assemble/disassemble and repair field equipment	Varies	All
Signage	Inform public on management activities and local regulations	Metal signs near traps, flyers, press releases, media coverage	All
Air-activated heat packets	Keep cold sensitive items warm while in the field (i.e. immobilizing drugs)	HotHands® Hand Warmers (Home Depot SKU 513219)	Capture
Batting Helmet	For use by personnel in clover trapping during restraint	Rawlings® Softball Helmet w/ mask	Capture
Box-trap	Live-capture	Medium Wildlife Capture Services Box-trap	Capture
Car Battery Charger	Charge 12 volt batteries	Varies	Capture
Drop-Net	Live-capture groups of animals	40' x 40' Wildlife Capture Services Drop-Net System	Capture
Drop-Net Batteries	Power electromagnets on drop-net	Deep Cycle marine 12 volt battery	Capture
Heavy Duty T-Posts	Secure traps and trap support posts to ground	6ft. Green Steel Fence T-Post (Home Depot SKU 373311)	Capture
Hunting Blind	Hide net operators, reduce motion	Ameristep Doghouse Blind (Bass Pro Shops SKU 2581256)	Capture
Loppers/Machete	Clear vegetation from trap locations	Fiskars® Bypass Lopper (Home Depot SKU 643278)	Capture
Metal Chain	Attach traps and support posts to T-posts	#2/0 Stainless Steel Straight Link Chain (Home Depot SKU 263436)	Capture

Thermal Imaging Devices	Necessary for trapping at night	FLIR Systems Scout II 240	Capture
T-post driver	Drive T-posts into the ground	Metal Fence Post Driver (Home Depot SKU 108235)	Capture
T-post remover	Easily remove T-posts from ground	Post Pull'R (Home Depot SKU 517895)	Capture
Two-Way Radio	Allows direct communication between crew members; alert crew of captures	Midland® GXT1000VP4 Two-Way Radio	Capture
Whole Kernel Corn/Apples	Bait	Varies	Capture
Camera Traps	Monitor trap sites, activity at bait sites	Moultire® M-888 Mini Game Camera	Monitoring
Cellular Camera Traps	Monitor trap sites and activity at bait sites; remotely sends pictures	SPYPOINT® Link 3G	Monitoring
Lock Boxes	Metal protection housing for camera traps to deter damage or theft	SPYPOINT® SB-Pro Steel Security Box	Monitoring
Python Locks	Secure camera traps and other field supplies	Python Adjustable Lock (Home Depot SKU 577100)	Monitoring
Antibiotic Cream	Treat any wounds sustained during captures	Neosporin®	Processing
Biohazard Bags	Dispose of biological waste	Varies	Processing
Captive Bolt-Gun	Euthanize animals	BLITZ® Captive Bolt Gun Kit (QC Supply # 140760)	Processing
Digital Thermometer	Monitor rectal temperature	Varies	Processing
Ear Tag Applicator	Applies ear tag to animal	Destron Fearing™ Duflex® ProGrip™ II Universal Applicator (QC Supply Part # 140330)	Processing
Ear Tags w/ backing	Uniquely identify captured animals	Destron Fearing™ Duflex® Medium ID Ear Tags (Valley Vet Supply Item 20713)	Processing
Emergency Blankets	Warm up hypothermic animals	Emergency Blanket 87" x 59" (MCR Medical SB-1001-001)	Processing
EPI Pen Containers	Safe storage for syringes containing drugs while in the field	EPI PEN® Jr. plastic holster case	Processing
Ethanol Vials	Vials filled with 70% ethanol for collecting ticks	15mL tubes w/ 5mL of ethanol	Processing

Face Blinds	Reduces stress to captured animals	Full face hood/mask (Wildlife Capture Equipment SKU HD002-M)	Processing
Fishing Tackle Box	Organize, transport, and store processing equipment	Plano® XL 3-Tray Box (Bass Pro Shops SKU 1719875)	Processing
Forceps	Remove attached parasites	Varies	Processing
Gauze Pads	Clean, dress wounds during processing	Varies	Processing
Ice	Cool down hyperthermic animals	Varies	Processing
Immobilizing Agent	Used to safely process animals for extended periods of time	BAM™ Kit Wildlife Pharmaceuticals	Processing
Insulated Container	Preserve temperature sensitive items (i.e. drugs, samples)	Varies	Processing
Isopropyl Alcohol	Used to cool down hyperthermic animals; sterilize equipment	Varies	Processing
Measuring tape	Record morphometric data	Varies	Processing
Narcan®	Reverse effects of opioids in instance of accidental human exposure	Narcan®(naloxone HCL) Nasal Spray (ADAPT Pharma, Inc)	Processing
Nitrile Gloves	Processing and handling of all wildlife animals	Varies	Processing
Oxygen Tanks	Provide supplemental oxygen to anesthetized animals	Size E Cylinder with Regulator (AirGas #OX USPEAWB)	Processing
Permanent Markers	Marking vials, tags, and data sheets	Varies	Processing
Pulse Oximeter	Monitor blood oxygen saturation	SurgiVet® v1030 (Smiths Medical)	Processing
Reversal Agent	Reverse animals from anesthetization	Atipamezole and Naltrexone Wildlife Pharmaceuticals	Processing
Saline Solution	Flush out debris from any wounds	Varies	Processing
Saw	Clear vegetation or remove antlers in emergency situation	Hacksaw (Home Depot SKU 1000032953)	Processing
Sharps Container	Dispose of used syringes and needles	Varies	Processing
Split Cannula	Administer oxygen to multiple animals at once with one tank	Varies	Processing
Syringes w/ needles	Deliver immobilizing drugs	5mL Nipro Luer Lock Syringes 21 gauge 1 inch needles	Processing

Tarps	Thermal insulation for processing animals	Varies	Processing
Water Coolers	Store and transport ice	Varies	Processing
Wax Pens	Mark injection site to avoid contact after delivering drugs	Raidex Prima Tech marking sticks (QC Supply #140150)	Processing

Disclaimer: The following is a description of equipment used in this suburban white-tailed deer trapping study, but is not meant to be comprehensive or absolute. Methodology for processing and handling deer may differ based on experience, IACUC protocols, study design and objectives.

[1]Supplies are grouped into four main aspects of trapping: Capture-preparation and set up of traps; Monitoring-monitoring of trap sites and animal activity; Processing- safely processing and collecting samples from immobilized animals; All- Imperative for all aspects of trapping

Appendix C

Table C.1. Percent Habitat Cover within study site buffer zones. NLCD 2016 land cover class names are used.

Park	Water	Open_Space	Developed_Low	Developed_Med	Developed_High	Barren	Deciduous	Ever-green	Mixed	Shrub_Scrub	Herbac-eous	Pasture	Crops	Wetlands*
Cedar Lane Park	0.44	26.9	15.16	5.76	0.81	0.02	23.39	0.05	4.18	0.15	0.71	18.98	3.23	0.22
Middle Patuxent Environmental Area	0.09	22.53	17.76	4.04	0.37	0.03	42.12	0.11	2.67	0.32	0.38	7.58	0.32	1.68
Wincopin Trails System	0.73	23.37	23.01	7.84	0.58	0.2	34.7	0.06	1.34	0.22	0.91	6.55	0.2	0.3
Rockburn Branch Park	0.04	29	19.59	4.1	0.68	0.06	32.3	0.07	3.41	0.75	0.98	8.67	0.29	0.06
Blandair Regional Park	0.46	36.4	23.37	10.34	1.7	0.07	19.88	0.14	3.41	1.44	0.27	1.02	0.23	1.26

* “Wetland” cover class combines “Woody Wetlands” and “Herbaceous Emergent Wetlands” cover classes from NLCD 2016

Table C.2. Percentage of land use cover within study site buffer zones. Howard County Land Use class names used.

Park	**Residential Land**	**Parks/Open Space**	**Institution**	**Utility**	**Commercial**	**Industrial**	**Undeveloped Land***
Cedar Lane Park	60.58	26.88	8.31	0.37	2.35	0	1.51
Middle Patuxent Environmental Area	43.7	44.37	4.08	0.14	2.58	0	5.13
Wincopin Trails System	34.92	37.1	8.7	0.9	1.55	0.45	16.38
Rockburn Branch Park	43.24	38.81	4.6	3.46	1.11	0	8.78
Blandair Regional Park	45.44	32.77	8.23	1.2	10.4	1.09	0.87

* Undeveloped Land includes all classes of undeveloped land types (Undeveloped Residential, Undeveloped Institution, Undeveloped Utility, Undeveloped Commercial, Undeveloped Industrial)

Table C.3 Residential building density for each study site buffer zone.

Park	Size (ha)	# Residential Buildings	Residential Buildings/ha
Cedar Lane Park	1652	3995	2.42
Middle Patuxent Environmental Area	1821	4507	2.47
Wincopin Trails System	1449	4576	3.16
Rockburn Branch	1449	3617	2.5
Blandair Regional Park	1449	5469	3.77

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