Impacts of Coyotes (*Canis latrans*) on White-tailed Deer (*Odocoileus virginianus*) Behavior and Mortality in the Chicago Region

THESIS

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Abstract

White-tailed deer (*Odocoileus virginianus*) and coyotes (*Canis latrans*) have spread into metropolitan areas in recent decades. How these species interact with the landscape, other species, and each other is of interest to managers of these human-dominated areas. In the Chicago region, little is known about the relationship of white-tailed deer and coyotes. Our study aimed to elucidate the predator-prey relationship as well as how white-tailed deer respond behaviorally to coyotes as a result of this relationship. To answer questions on the predator-prey relationship between these two species, 81 white-tailed deer fawns were collared and monitored to determine causes of mortality. The analysis of 172 coyote scats also provided insight into this relationship by determining dominant food sources. Predation by coyotes was the primary cause of mortality (77.8%) of white-tailed deer fawns at our study site. Furthermore, white-tailed deer remains were found in most coyote scats (53.5%) but the presence of these remains were highest in scats collected in the summer (83.9% in 2017; 61.3% in 2018). The results of the fawn mortality analysis and scat analysis suggest that there are high incidents of coyote predation on white-tailed deer fawns but provide little evidence of predation on adults. With this specific predator-prey relationship, there is potential for behavioral asymmetries between age classes and sexes of white-tailed deer. To determine how this relationship influences white-tailed deer behavior, we chose to study antipredator behaviors because these behaviors are expressed in relation to predation risk. Following the "ecology of fear" framework, we expected to see increases in antipredator behavior by fawns and does with fawns in response to coyotes. We predicted, however, that the overall white-tailed deer population at our study site would not show strong antipredator behavior towards coyotes due to the possibility of habituation as a result of exposure to high coyote densities. We chose to investigate the antipredator behaviors of vigilance and avoidance in response to coyotes. Through the use of camera traps, we captured white-tailed deer foraging behavior in response to an indicator of coyote presence, specifically coyote urine. Through this test, we found that white-tailed deer of each age class and sex do not increase the amount of time spent vigilant while foraging when an indicator of coyote presence was present. To look for signs of avoidance of coyotes, white-tailed deer and coyotes were fitted with radio collars and monitored concurrently. Home range overlap was found for all deer-coyote dyads studied indicating that white-tailed deer are not selecting home ranges that allow the complete avoidance of coyotes. After analysis using the half-weight association index, however, results suggested avoidance behavior occurred for all deer-coyote dyads. These results show that the white-tailed deer monitored in our study avoid being within 200 m of coyotes. The results of both the vigilance survey and avoidance testing provide evidence of habituation, regardless of age class and sex, to an indicator of coyote presence and the lack of avoidance at the landscape level. These results, however, indicate that white-tailed deer at this site show finer-scale avoidance by avoiding coming into close proximity with coyotes. Our study provides valuable information on the coyote-deer predator-prey relationship and the behavioral responses of deer to this relationship in the Chicago region.

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Chapter 1: A Review of White-tailed Deer Behavior and Ecology in Urban Landscapes

INTRODUCTION

In recent decades, white-tailed deer (*Odocoileus virginianus*) and coyotes (*Canis latrans*) have colonized metropolitan areas and suburbs of the eastern half of the United States (Waller and Alverson 1997, Ditchkoff et al. 2006, Gehrt 2007). Historically, these species were found only in non-urban landscapes. By altering their behaviors, white-tailed deer and coyotes have found means to live within human-dominated landscapes. To accomplish this, in some human inhabited areas, populations of these species have adjusted their activities to times of day that allow temporal avoidance of humans, occupied home ranges of decreased size, and consumed a diet that best utilizes the landscape and the resources available (Etter et al. 2002, Gehrt 2007, Newsome et al. 2015). These variances in behavior among wildlife populations residing in urban and natural landscapes suggest other potential behavioral asymmetries.

Coyotes and white-tailed deer are the focal species for many urban wildlife studies, largely in part to their impacts on the landscape. Coyotes can be a danger to pets, spread disease, and impact the species upon which they prey (Gehrt and Riley 2010). White-tailed deer can create extensive damage to plant communities, such as forests and urban landscaping, (Waller and Alverson 1997), facilitate the spread of diseases including lyme disease (Telford et al. 1988), and serve as a safety hazard to both humans and deer via vehicle collisions (Stout et al. 1993, Kilpatrick et al. 2007). Despite these concerns, urban coyote and deer behavior research in particular is limited. Urban coyote studies have primarily focused on disease presence (Grigione et al. 2014, Liccioli et al. 2015, Aher et al. 2016, Klein et al. 2019), habitat use (Gehrt et al. 2009, Gese et al. 2012, Mitchell et al. 2015, Murray and St. Clair 2017, Lombardi et al. 2017, Moll et al. 2018, Greenspan et al. 2018), movement (Atwood et al. 2004, Way 2007, Poessel et al. 2016), diet (Newsome et al. 2015, Larson et al. 2015, Murray et al. 2015, Santana and Armstrong 2017), and coyote-human interactions (White and Gehrt 2009, Alexander and Quinn 2011, Baker and Timm 2017, Poessel et al. 2017*a*, Bombieri et al. 2018). The majority of urban deer studies focus on habitat use (Anderson et al. 2011, Urbanek and Nielsen 2013, Magle et al. 2014, McCance et al. 2015*b*, Gallo et al. 2017), movement (Porter et al. 2004, Gilman et al. 2010, McCance et al. 2015*a*), intersexual social behaviors (Richardson and Weckerly 2007), and deterrent methods (VerCauteren et al. 2005, Hildreth et al. 2013). Recently, individual personality and behavior of deer and coyotes has been studied, but this research has focused on the role that these individual characteristics play in deer management (Honda et al. 2018) and how they compare between urban and rural coyote populations (Breck et al. 2019).

As a result of the limited behavioral research available, little is known about how white-tailed deer respond behaviorally to coyote presence in metropolitan areas. In natural areas, coyotes have been observed depredating on adult white-tailed deer (MacCracken and Uresh 1984, Messier et al. 1986, Cherry et al. 2016*b*). In many metropolitan areas, however, it has been discovered that coyotes rarely prey upon adult white-tailed deer (Etter et al. 2002, Santana and Armstrong 2017) and instead hunt and consume fawns (Saalfeld and Ditchkoff 2007, Piccolo et al. 2010, Grigione et al. 2011, Poessel et al. 2017*b*). In the city of Chicago and its surrounding suburbs (hereafter “Chicago region”), this predation pattern has been observed (Etter et al. 2002, Morey et al. 2007, Piccolo et al. 2010). Research on the interactions and relationship between urban deer and coyotes is important because of the expectation that urbanization will continue to spread and the likelihood that these species will continue to use these areas.

ANTIPREDATOR BEHAVIOR

Recent research on the behavioral responses of prey has shown increased consideration of the "ecology of fear" conceptual framework (Clinchy et al. 2013). This framework indicates that fear experienced by prey as a result of potential predation can lead to behaviors aimed to ameliorate the threat (Brown et al. 1999). Historically, predator-prey systems were viewed as a linear function where predators would capture and kill seemingly "sessile" prey. However, as described by Brown et al. (1999), predator-prey systems are far more complex than traditionally thought. The concept of fear exhibited by prey adds a responding element to the actions of predators resulting in manipulation and strategy used on either side of this system. The presence of predators results in actions performed by prey as a result of fear of predators and the potential for a predation event. These behaviors, also known as antipredator behaviors, can be expressed by fleeing, hiding, and fighting a perceived threat, as well as increased observation to identify potential threats (Kavaliers and Choleris 2001).

In addition to the "ecology of fear" framework, there is potential for predation risk to elicit a change in how a prey species uses a landscape. This theory has been coined the "landscape of fear" (Laundré et al. 2010). With this concept, it is predicted that a prey species will use different locations within an area in unique ways as a response to fear experienced by that animal. It is believed through this idea that prey species can learn and decide how to respond to different levels of predation risk. This concept supports the idea that prey species use both habitat characteristics and terrain, in addition to signs of predator presence, as indicators of predation risk.

The ideas of both the "ecology of fear" and the "landscape of fear" provide structure to help the understanding of predator-prey systems. These frameworks indicate the ways and extent in which predators influence prey beyond the act of predation. Researchers can use these ideas to greater understand the behaviors, as well as the motivations for these behaviors, of the species within predator-prey systems. Furthermore, researchers can use these frameworks to help predict how prey species will utilize landscapes in which they co-inhabit with predators. This information helps with the understanding of the species within a system as well as how those species might influence that system.

WHITE-TAILED DEER IN URBAN LANDSCAPES

Ecology Review

White-tailed deer populations have increased locally throughout their range since the first protective laws for this species were enacted in the early 1900s (VerCauteren 2003). Furthermore, white-tailed deer have spread into metropolitan areas in recent decades. This species has proven to thrive in human-dominated landscapes through the usage of greenspaces intermixed within these areas (DeNicola et al. 2000). For example, white-tailed deer inhabit a variety of green spaces within the Chicago region including cemeteries, golf courses, and natural areas (Gallo et al. 2017). This species is also known to utilize spaces in close proximity to humans when an abundance of resources are available in those spaces. A study conducted in Winnipeg, Manitoba, observed residential yard usage by white-tailed deer and found that this usage is highly correlated to human-supplied food sources (McCance et al 2015*b*). Previous research has also suggested that the use of residential yards increases during the winter months when natural resources are more difficult to acquire (Kilpatrick and Spohr 2000, Grund et al. 2002).

The home ranges of urban white-tailed deer tend to be smaller than those of their rural counterparts (Henderson et al. 2000, Kilpatrick et al. 2001, Grund et al. 2002, Porter et al. 2004, Storm et al. 2007, Walter et al. 2011). Urban deer also show strong site fidelity and low dispersal rates (Kilpatrick and Lima 1999, Kilpatrick et al. 2001, Grund et al. 2002, Porter et al. 2004). Home ranges, site fidelity, and dispersal are influenced by habitat characteristics and connectivity (Walter et al. 2009). Therefore, the limited habitat availability and connectivity in urban areas are believed to result in the smaller home ranges, high site fidelity, and low dispersal of urban deer populations.

White-tailed deer in urban areas experience higher levels of survival than those of rural areas because of reduced hunting pressure and low predator numbers (Swihart et al. 1995, Etter et al. 2002, Storm et al 2007). This increased survival rate has likely facilitated the burgeoning population densities in many urban areas. White-tailed deer in urban landscapes occur in higher densities than deer of rural landscapes (Swihart et al. 1995, DeNicola et al. 2000). Because of these high densities and the problems that follow high density populations, early urban white-tailed deer research primarily focused on methods of population control (e.g. Garrott 1995, Butfiloski et al. 1997, DeNicola et al. 1997, Messmer et al. 1997).

Behavior Review

The intersexual social behavior of urban white-tailed deer appears to be indistinct from rural populations. Similar to their rural counterparts, urban doe-only and mixed-sex foraging groups tend to be larger than male-only groups (Richardson and Weckerly 2007). Richardson and Weckerly (2007) also found that males tend to show more aggressive behaviors toward others, a behavior also observed in rural populations. Urban deer also exhibit the same matrilineal social structure as observed in rural populations (Crawford et al. 2018). Socially, female relatives tend to aggregate and remain in or near natal home ranges while males tend to disperse.

Research on the antipredator behaviors of urban deer is scant. Two studies examining the response of deer to humans in areas of high recreational activity provide some information on how the antipredator behavior of this species can vary based on threat exposure. White-tailed deer were found to have a lower flight distance in an Illinois state park with high human visitation than one with low human visitation (Sutton and Heske 2017). The authors believed that these results provided evidence that the deer in these parks either habituated to human presence or were segregated by personality. Similarly, a study across six southeastern states found that deer showed decreased vigilance while foraging in areas of high human activity (Schuttler et al. 2017). These results further suggest that deer become habituated to human presence.

Considering the limited literature available on urban white-tailed deer behavior, we could conclude that the social structure of urban deer is similar to rural populations. We could also conclude that urban deer have the ability to fluctuate their antipredator behavior to follow varying threat levels. However, further research is needed to determine whether these results are observed in all urban deer populations and whether other unstudied factors may influence these behaviors. A study conducted in Texas found that urban deer foraging in larger groups reacted less intensely to vehicle presence than smaller groups, but that the relationship between these two factors was weak (Richardson and Weckerly 2007). These results provide further evidence that antipredator behavior is potentially influenced by factors other than predator presence. The results of Richardson and Weckerly (2007) also lend insight into how the intensity of an antipredator behavior can be influenced by nearby conspecifics. White-tailed deer are known to congregate in groups to alleviate some risk of predation. How this behavior and other antipredator behaviors of deer within these groups materialize in urban landscapes is yet to be explored.

WHITE-TAILED DEER AND COYOTE RELATIONSHIP

Relationship in Chicago and Other Areas

Coyotes are known to hunt and consume adult white-tailed deer in some rural areas (MacCracken and Uresh 1984, Huegel and Rongstad 1985, Messier et al. 1986, O'Gara and Harris 1988, Whitlaw et al. 1998, DePerno et al. 2000, Patterson and Messier 2003, Moratz et al. 2018), including areas which coyotes have only recently occupied (Chitwood et al. 2014, Cherry et al. 2016*b*, Benson et al. 2017, Hinton et al. 2017, Ward et al. 2018). Researchers also found that deer densities can influence the movement and space use of coyotes in some rural areas. In Nova Scotia, researchers found coyotes used areas within their territories with higher deer densities more than ones with low deer densities during the winter (Patterson and Messier 2001). Similarly, a study in Québec found that coyotes increased utilization of deer wintering areas within their home ranges more during the winter and spring (Crête et al. 2001).

White-tailed deer fawns are known to be a major summer food source of coyotes in areas where the two species coexist (Schrecengost et al. 2008). Coyotes are known to increase deer consumption after the pulsed resource event of parturition (Petroelje et al. 2014). Coyote predation is often a major source of fawn mortality (Long et al. 1998, Ballard et al. 1999, Whittaker and Lindzey 1999, Lingle 2000, Vreeland et al. 2004, Rohm et al. 2007, Grovenburg et al. 2012, McCoy et al. 2013, Chitwood et al. 2017, Hasapes and Comer 2017, Shuman et al. 2017) but not in all areas (Burroughs et al. 2006). The habitat quality and land cover available at the study site of the Burroughs et al. (2006) fawn survival study was believed to contribute to the high fawn survival rate observed in that study. There is also evidence to suggest that coyotes will largely consume fawns even when other available prey densities are high because it may be more energetically efficient for coyotes with pups to kill fawns than other smaller prey (Patterson et al. 1998).

Coyote predation has shown to be an additive source of mortality for fawns at a rural site in South Carolina, inferring potential for this effect to be observed in other areas (Kilgo et al. 2014). Another white-tailed deer fawn survival study observed an increase in fawn recruitment after coyote removal, suggesting that coyote densities can influence white-tailed deer populations (Gulsby et al. 2015). Furthermore, coyotes were found to influence recruitment in ways outside of predation in South Carolina (Cherry et al. 2016*a*). The results of Cherry et al. (2016*a*) indicated that after the removal of coyotes, female deer showed increased incidence of ovulation and lactation. These results suggest that female deer can suppress reproduction when the risk of predation is high. Similarly, the results of a study of fawn survival in Alabama found that low recruitment was likely driven by coyote predation (Jackson and Ditchkoff 2013).

Although coyotes have been shown to influence white-tailed deer populations in some areas, minimal effects were observed in other areas. For example, a study conducted in Minnesota found that deer consumption was low and that coyotes spent more time searching areas that were not associated with fawning (Turner et al. 2011). These results suggest that coyotes are not a strong influence on the deer population at this site. A substantial review on predator influence on deer populations found that only when the population was below forage carrying capacity did deer mortality decrease when predator populations were reduced (Ballard et al. 2001). These results suggest that food availability is a stronger influence than coyote predation on deer populations.

Previous research shows that the Chicago region populations of both coyotes and white-tailed deer have a specific predator-prey relationship. As found by Morey et al. (2007) and Piccolo et al. (2010), coyotes in the Chicago metropolitan area rarely kill adult white-tailed deer, but are believed to be the main cause of mortality of fawns. Through scat analysis, Morey et al. (2007) found that deer are an important food source for coyotes in the Chicago region. Morey et al. (2007) believed that most occurrences of deer remains found within coyote scat were from carrion and fawns because of the high amount of road-killed deer available at the study sites and the presence of fawn remains in scat. Piccolo et al. (2010) found that fawn survival varied between two suburban forest preserves in Chicago, but that the main source of mortality was coyote predation at both sites (50% and 86%). Similar to other fawn mortality studies, a majority of the fawn mortalities at these sites occurred within the first month of life.

Research on the coyote-deer predator-prey relationship in other areas of increased human activity found similar results to those of the Chicago region. A fawn survival study in an exurban area of Alabama found that coyotes were the main cause of mortality for fawns (Saalfeld and Ditchkoff 2007). The results of Saalfeld and Ditchkoff (2007), in conjunction with Piccolo et al. (2010), suggest that coyotes are a threat to white-tailed deer fawns in human-dominated landscapes. How this predation risk influences urban deer behavior is mostly unknown.

Behavioral Responses to Coyotes

A Chicago study on the behavior of deer in response to coyotes found that the focal antipredator behavior -avoidance- in the Chicago region did not mirror areas where adult deer predation has occurred (Magle et al. 2014). It is possible that the lack of predation on adult white-tailed deer by coyotes may create a less fearful white-tailed deer population. A less fearful white-tailed deer population may not avoid coyotes and select habitats like a more fearful population would.

Avoidance can be used to gauge fear in white-tailed deer because of the responses deer are known to exhibit when threatened. White-tailed deer are known to flee when a predation attempt is made by a coyote (Lingle 2001). It has also been found that when white-tailed deer are alerted to coyote presence from a long distance, further pursuit by a coyote was less likely than at shorter distances (Lingle and Wilson 2001). These observations provide evidence that by fleeing, white-tailed deer are able to avoid some predation events. These behaviors also indicate that avoidance would be observed between deer and coyotes if there is substantial threat.

Avoidance occurs both spatially and temporally (Lima 1998). Avoidance can also be present at varying scales. A study conducted in New York deduced that coyotes have the ability to alter white-tailed deer browsing behavior within an area of co-inhabitance (Pierce et al. 2015).

Although not conducted in an urban area, the Pierce et al. (2015) study provides insight into the scale at which white-tailed deer behavior can change in response to coyote presence. Signs of browsing were used in that study to determine the locations of white-tailed deer foraging, and coyote scat was used to determine the predation risk for deer. Pierce et al. (2015) found that evidence of browsing by white-tailed deer shifted from forest edges to forest interior when coyote scat was found in preferred browsing locations along the forest edge. Signs of browsing, however, did not change at the transect scale when coyote scat was also found along the same transect. With the premise of the "landscape of fear" hypothesis, it was predicted by the authors that white-tailed deer should have avoided coyotes to a greater extent. Greater avoidance would have been evident by the lack of browsing signs when coyote scat was found in the same area and an abundance of browsing signs when coyote scat was absent. The Pierce et al. (2015) study is an example of the variability in behavioral response deer can exhibit with the same indicator of coyote presence.

Another study, conducted in the suburban area of Lee's Summit and Warrensburg, Missouri (Jones et al. 2016), used camera trapping to determine whether coyotes influenced the presence of white-tailed deer, as well as multiple squirrel species (*Sciurus spp.*) and cottontail rabbit (*Sylvilagus floridanus*). Jones et al. (2016), which also used the "ecology of fear" and "landscape of fear" frameworks as a guide, found that coyote presence had a negative effect on the presence of the studied prey species. The authors compared their work to the study by Magle et al. (2014) in Chicago and determined that the "landscape of fear" hypothesis was supported in their study, because the Missouri suburban landscape contained more quality habitat than the landscape in the Chicago study.

Despite a lack of predation in some areas, there is evidence that deer may avoid coyotes across these species' range. Other studies found that some prey species may fear predator species even when actual predation by those species is not occurring in that ecosystem (Lima 1998). Many behaviors, however, are the product of experiences that vary for each individual. Annually, coyotes are the bigger threat to uninhibited fawns, during spring and early summer, from parturition to two weeks old (Rohm et al. 2007). Outside of the two week timeframe, there is potential for deer to become habituated to coyotes in high density areas with little adult deer predation.

Throughout coyote avoidance research, white-tailed deer behavior is not consistent across studies. As previously mentioned, the suburban study in Missouri (Jones et al. 2016) and the rural study in New York (Pierce et al. 2015) found that white-tailed deer do avoid coyotes. However, the severity of this avoidance, type of habitat, and data collection methods of these studies differed. The Missouri study used camera trapping to determine that coyote presence had a negative effect on white-tailed deer presence within a suburban area (Jones et al. 2016). Pierce et al. (2015) found that evidence of white-tailed deer browsing shifted closer to the forest interior when coyote scat was found along forest edges in a natural area of New York. Although these two studies found avoidance of coyotes by white-tailed deer, other avoidance studies found differing results. For example, the Chicago study investigating white-tailed deer avoidance of coyotes found through the use of camera surveys that deer utilize the same areas as coyotes and that there was a positive association between the observance of coyotes and deer (Magle et al. 2014). Magle et al. (2014) provides evidence that these populations occupy the same areas within the landscape and that the predation risk was not great enough to elicit avoidance. A rural

Michigan study also found a positive association in the presence of white-tailed deer with that of coyotes. The driver of the observed behavior in the Michigan study, however, is different than that in Chicago. The Michigan study found that female deer avoid areas of high wolf activity, thereby utilizing areas with greater coyote activity (Duquette et al. 2014). Although fawn mortality was high as a result of coyote predation, the authors believed that this strategy improved the reproductive success of the does because of increased adult deer survival in coyote dominated areas. It is important to note, however, that each of these studies of deer avoidance in response to coyote presence utilized indirect methods to assess avoidance and not direct evidence.

Vigilance, another antipredator behavior, is also used as a measure of predation risk for a variety of species. Many cervid species, including white-tailed deer, exhibit vigilant behavior while foraging in landscapes where there is potential predation (Waser et al. 2014, Cherry et al. 2015). Vigilant behavior is characterized by spending time looking around for predators instead of feeding during foraging. Because of the foraging trade-off, time spent vigilant versus time spent foraging can be used to gauge predation risk. If predation risk is high, it would be expected that white-tailed deer would be more vigilant (and therefore spend less time foraging) than if predation risk were low.

Methods used by previous white-tailed deer vigilance studies varied in terms of data collection and predator presence simulation. One way to test vigilant behavior while foraging is through the use of baited sites. Previous studies have baited with corn (Gulsby et al. 2018) or set up feed blocks (Waser et al. 2014) and observed cervid species while foraging. Indicators of coyote presence used in other deer response studies include actual coyote presence (Gulsby et al.

2018), coyote urine (Swihart et al. 1991, Waser et al. 2014), and coyote hair (Seamans et al. 2002).

Although actual coyote presence allows researchers to directly observe the effects of coyotes, most studies do not have the ability to exclude predators from sites to compare deer behavior. Therefore, most studies use some sort of indicator of coyote presence to study how white-tailed deer respond to coyotes. In a study conducted in Connecticut, researchers tested how treatments of bobcat, coyote, human, and rabbit urine affected browsing on a common food source of white-tailed deer (Swihart et al. 1991). It was found that browsing decreased significantly when treated with urine of a predator (i.e. bobcat and coyote). It was found, however, that this behavior was influenced by what type of plant the urine was near (deer responded stronger to predator urine when on plants that were the least palatable). Coyote urine was found to reduce browsing in other white-tailed deer foraging studies as well (Champagne et al. 2018), suggesting that it sufficiently indicates predator presence. The chemical 2-phenylethylamine is produced greater in carnivore species and is believed to be the olfactory cue for prey species to identify predator presence (Ferrero et al. 2011). This chemical is found in predator urines and research has suggested that the presence of this chemical can evoke antipredator behaviors. It was found that coyote hair works in a similar fashion to coyote urine in altering feeding behavior. In a study conducted in Ohio, coyote hair was placed at feed sites and along established deer trails (Seamans et al. 2002). There was a significant decrease in the amount of feed consumed and the number of deer that entered the feed sites when coyote hair was present. The presence of coyote hair, however, did not alter the use of established deer trails by deer. Seamans et al. (2002) gives insight into how a common predator indicator can provoke an antipredator behavior (e.g. avoidance) in specific scenarios, but not in all. Furthermore, a later study found that the presence of coyote hair increased alert behavior at foraging sites (Seamans et al. 2016).

In one study of white-tailed deer vigilance, the behavior of white-tailed deer while foraging was observed during normal and predator-excluded conditions in Georgia (Cherry et al. 2015). Researchers used cameras to observe the foraging behavior of white-tailed deer. The deer were listed as either feeding or vigilant in captures. When predators were excluded from areas where white-tailed deer were foraging, there was a 5% and 13.4% increase in feeding behavior in females and males, respectively. These increases in antipredator behavior were observed during seasons in which the sexes are most vulnerable to predation. Summer has greater predation risk for females and winter has a greater risk for males (Ballard 2011). The results of Cherry et al. (2015) provide evidence that white-tailed deer antipredator behavior can be influenced by coyote presence at their study site. These results also imply that male white-tailed deer in the Cherry et al. (2015) study area participate in stronger antipredator behavior than females, although these results may be influenced by the differences in male and female group foraging behavior. These methods and results offer a way to observe deer behavior remotely as well as showing how coyotes can influence members of a white-tailed deer population.

A similar study in Georgia investigated how coyote densities influenced vigilant behavior while foraging (Gulsby et al. 2018). Through the use of trail cameras, Gulsby et al. (2018) found that female white-tailed deer respond greater to high coyotes densities in the summer than at other times of the year and males respond greater in the winter. These results, alongside those of Cherry et al. (2015), support the belief that deer alter their vigilance in areas and during seasons of greater predation risk. The results of a large-scale vigilance study, however, did not corroborate this idea. Schuttler et al. (2017) found that coyote activity did not result in increased vigilance while foraging in natural areas across six southeastern states. The results of Schuttler et al. (2017) indicate that deer responses to coyotes are not homogenous throughout their range.

Although vigilance is a response to predation risk, other factors can influence this behavior. It was found that group size, sex, and other non-predator presence factors can impact individual vigilance of white-tailed deer. A study in North Carolina observed that deer decreased vigilant behavior in larger groups, but that males were more strongly influenced by each additional deer to the groups (Lashley et al. 2014). Lashley et al. (2014) found that vigilance increased when non-predator species were present. These results provide evidence that vigilant behavior can be influenced by factors other than predation risk.

CONCLUSION

Although many studies on white-tailed deer exist, the predator-prey and behavioral relationship between deer and predators such as coyotes in urban areas is largely understudied. Recently, behavioral research has considered the “ecology of fear” and “landscape of fear” frameworks in their development of studies and as an explanation for observed behavior. The expected results when following these frameworks, however, has not always been reliable. The unique ecology of urban systems has potential to stray from blanket concepts developed using rural populations. Knowledge of urban deer and coyotes provide evidence that these populations may show some behavioral differences from their rural counterparts. The predator-prey relationship of the coyotes and deer in the Chicago region give indication that the behavior of deer in response to coyotes may not mirror that of deer in rural landscapes.

LITERATURE CITED

Aher, A. M., D. Caudill, G. Caudill, R. S. Butryn, D. Wolf, M. Fox, D. P. Blake, and M. W. Cunningham. 2016. Prevalence, genetic analyses, and risk factors associated with heartworm (Dirofilaria immitis) in wild coyotes (Canis latrans) from Florida, USA. 2016. Journal of Wildlife Diseases 52:785-792.

Alexander, S. M., and M. S. Quinn. 2011. Coyote (Canis latrans) interactions with humans and pets reported in the Canadian print media (1995-2010). Human Dimensions of Wildlife 16:345-359.

Anderson, C. W., C. K. Nielsen, D. J. Storm, and E. M. Schauber. 2011. Modeling habitat use of deer in an exurban landscape. Wildlife Society Bulletin 35:161-167.

Atwood, T. C., H. P. Weeks, and T. M. Gehring. 2004. Spatial ecology of coyotes along a suburban-to-rural gradient. Journal of Wildlife Management 68:1000-1009.

Baker, R. O., and R. M. Timm. 2017. Coyote attacks on humans. 1970-2015: Implications for reducing the risks. Human-Wildlife Interactions 11:120-132.

Ballard, W. B. 2011. Impacts on ecosystems. Pages 251-286 in: D. G. Hewitt, editor. Biology and management of white-tailed deer. CRC Press, Boca Raton, Florida, USA.

Ballard, W. B., D. Lutz, T. W. Keegan, L. H. Carpenter, and J. C. deVos, Jr. 2001. Deer-predator relationships: A review of recent North American studies with emphasis on mule and black-tailed deer. Wildlife Society Bulletin 29:99-115.

Ballard, W. B., H. A. Whitlaw, S. J. Young, R. A. Jenkins, and G. J. Forbes. 1999. Predation and survival of white-tailed deer fawns in northcentral New Brunswick. Journal of Wildlife Management 63:574-579.

Benson, J. F., K. M. Loveless, L. Y. Rutledge, and B. R. Patterson. 2017. Ungulate predation and ecological roles of wolves and coyotes in eastern North America. Ecological Applications 27:718-733.

Bombieri, G., M. M. Delgado, L. F. Russo, P. J. Garrote, J. V. López-Bao, J. M. Fedriani, and V. Penteriani. Patterns of wild carnivore attacks on humans in urban areas. Scientific Reports 8:17728.

Breck, S. W., S. A. Poessel, P. Mahoney, and J. K. Young. 2019. The intrepid urban coyote: a comparison of bold and exploratory behavior in coyotes from urban and rural environments. Scientific Reports 9:2104.

Brown, J. S., J. W. Laundré, and M. Gurung. 1999. The Ecology of Fear: Optimal Foraging, Game Theory, and Trophic Interactions. Journal of Mammalogy 80:385–399.

Burroughs, J. P., H. Campa III, S. R. Winterstein, B. A. Rudolph, and W. E. Moritz. 2006. Cause-specific mortality and survival of white-tailed deer fawns in southwestern lower Michigan. Journal of Wildlife Management 70:743-751.

Butfiloski, J. W., D. I. Hall, D. M. Hoffman, and D. L. Forster. 1997. White-tailed deer management in a coastal Georgia residential community. Wildlife Society Bulletin 25:491-495.

Champagne, E., L. Perroud, A. Dumont, J. –P. Tremblay, and S. D. Côté. 2018. Neighboring plants and perception of predation risk modulate winter browsing by white-tailed deer (Odocoileus virginianus). Canadian Journal of Zoology 92:117-125.

Cherry, M. J., L. M. Conner, and R. J. Warren. 2015. Effects of predation risk and group dynamics on white-tailed deer foraging behavior in a longleaf pine savanna. Behavioral Ecology arv054. doi:10.1093/beheco/arv054.

Cherry, M. J., K. E. Morgan, B. T. Rutledge, L. M. Conner, and R. J. Warren. 2016*a*. Can coyote predation risk induce reproduction suppression in white-tailed deer? Ecosphere 7(10): e01481.

Cherry, M. J., K. L. Turner, M. B. Howze, B. S. Cohen, and L. M. Conner. 2016*b*. Coyote diets in a longleaf pine ecosystem. Wildlife Biology 22:64–70.

Chitwood, M. C., M. A. Lashley, C. E. Moorman, and C. S. DePerno. 2014. Confirmation of coyote predation on adult female white-tailed deer in the southeastern United States. Southeastern Naturalist 13:N30-N32.

Chitwood, M. C., M. A. Lashley, C. E. Moorman, and C. S. DePerno. 2017. Setting an evolutionary trap: could the hider strategy be maladaptive for white-tailed deer? Journal of Ethology 35:251-257.

Clinchy, M., M. J. Sheriff, and L. Y. Zanette. 2013. Predator-induced stress and the ecology of fear. Functional Ecology 27:56-65.

Crawford, J. C., A. Dechen Quinn, D. M. Williams, B. A. Rudolph, K. T. Scribner, and W. F. Porter. 2018. Fine-scale spatial genetic structure of deer in a suburban landscape. Journal of Wildlife Management 82:596-607.

Crête, M., J. –P. Ouellet. J. –P. Tremblay, and R. Arsenault. 2001. Suitability of the forest landscape for coyotes in northeastern North America and its implications for coexistence with other carnivores. Écoscience 8:311-319.

DeNicola, A. J., D. J. Kesler, and R. K. Swihart. 1997. Remotely delivered prostaglandin F(2α) implants terminate pregnancy in white-tailed deer. Wildlife Society Bulletin 25:527-531.

DeNicola, A. J., K. C. VerCauteren, P. D. Curtis, and S. E. Hygnstrom. 2000. Managing white-tailed deer in suburban environments: a technical guide. Cornell Cooperative Extension Information Bulletin, Cornell University, Ithaca, New York, USA.

DePerno, C. S., J. A. Jenks, S. L. Griffin, and L. A. Rice. 2000. Female survival rates in a declining white-tailed deer population. Wildlife Society Bulletin 28:1030-1037.

Ditchkoff, S. S., S. T. Saalfeld, and C. J. Gibson. 2006. Animal behavior in urban ecosystems: Modifications due to human-induced stress. Urban Ecosystems 9:5–12.

Duquette, J. F., J. L. Belant, N. J. Svoboda, D. E. Beyer Jr., P. E. Lederle. 2014. Effects of maternal nutrition, resource use and multi-predato risk on neonatal white-tailed deer survival. PLoS ONE 9(6):e100841.

Etter, D., K. Hollis, T. Van Deelen, D. Ludwig, J. Chelsvig, C. Anchor, and R. Warner. 2002. Survival and movements of white-tailed deer in suburban Chicago, Illinois. Journal of Wildlife Management 66:500-510.

Ferrero, D. M. J. K. Lemon, D. Fluegge, S. L. Pashkovski, W. J. Korzan, S. R. Datta, M. Spehr, M. Fendt, and S. D. Liberles. 2011. Detection and avoidance of a carnivore odor by prey. Proceedings of the National Academy of Sciences of the United States of America 108:11235-11240.

Gallo, T., M. Fidino, E. W. Lehrer, and S. B. Magle. 2017. Mammal diversity and metacommunity dynamics in urban green spaces: Implications for urban wildlife conservation. Ecological Applications 27:2330-2341.

Garrott, R. A. 1995. Effective management of free-ranging ungulate populations using contraception. Wildlife Society Bulletin 23:445-452.

Gehrt, S. D. 2007. Ecology of Coyotes in Urban Landscapes. Pages 303-311. Proceedings of the 12th Wildlife Damage Management Conference, Corpus Christi, Texas.

Gehrt, S. D., C. Anchor, and L. A. White. 2009. Home range and landscape use of coyotes in a metropolitan landscape: Conflict or coexistence? Journal of Mammalogy 90:1045-1057.

Gehrt, S. D., and S. P. D. Riley. 2010. Coyotes (Canis latrans). In: Gehrt SD, Riley SPD, Cypher BL (eds) Urban carnivores: ecology, conflict, and conservation. Johns Hopkins University Press, Baltimore, Maryland, USA pp 79–95.

Gese, E. M., P. S. Morey, and S. D. Gehrt. 2012. Influence of the urban matrix on space use of coyotes in the Chicago metropolitan area. Journal of Ethology 30:413-425.

Gilman, R. T., N. E. Mathews, B. G. Skinner, V. L. Julis, A. S. Frank, and J. Paul-Murphy. 2010. Effects of maternal status on the movement and mortality of sterilized female white-tailed deer. Journal of Wildlife Management 74:1484-1491.

Greenspan, E., C. K. Nielsen, and K. W. Cassel. 2018. Potential distribution of coyotes (Canis latrans), Virginia opossums (Didelphis virginiana), striped skunks (Mephitis mephitis), and raccoons (Procyon lotor) in the Chicago Metropolitan Area. Urban Ecosystems 21:983-997.

Grigione, M. M., P. Burman, S. Clavio, S. J. Harper, D. L. Manning, and R. J. Sarno. 2011. Diet of Florida coyotes in an protected wildland and suburban habitat. Urban Ecosystems 14:655-663.

Grigione, M. M., P. Burman, S. Clavio, S. J. Harper, D. L. Manning, and R. J. Sarno. 2014. A comparative study between enteric parasites if coyotes in a protected and suburban habitat. Urban Ecosystems 17:1-10.

Grovenburg, T. W., R. W. Klaver, and J. A. Jenks. 2012. Survival of white-tailed deer fawns in grasslands of the northern Great Plains. Journal of Wildlife Management 76:944-956.

Grund, M. D., J. B. McAninch, and E. P. Wiggers. 2002. Seasonal movements and habitat use of female white-tailed deer associated with an urban park. Journal of Wildlife Management 66:123-130.

Gulsby, W. D., M. J. Cherry, J. T. Johnson, L.M. Conner, and K. V. Miller. 2018. Behavioral response of white-tailed deer to coyote predation risk. Ecosphere 9(8): e02141.

Gulsby, W. D., C. H. Killmaster, J. W. Bowers, J. D. Kelly, B. N. Sacks, M. J. Statham, and K. V. Miller. 2015. White-tailed deer fawn recruitment before and after experimental coyote removals in central Georgia. Wildlife Society Bulletin 39:248-255.

Hasapes, S. K., and C. E. Comer. 2017. White-tailed deer fawn survival, home range, and habitat composition in northwest Louisiana. Wildlife Society Bulletin 41:499-507.

Henderson, D. W., R. J. Warren, J. A. Cromwell, and R. J. Hamilton. 2000. Responses of urban deer to a 50% reduction in local herd density. Wildlife Society Bulletin 28:902-910.

Hildreth, A. M., S. E. Hygnstrom, and K. C. VerCauteren. 2013. Deer-activated bioacoustics frightening device deters white-tailed deer. Human-Wildlife Interactions 7:107-113.

Hinton, J. W., A. K. Ashley, J. A. Dellinger, J. L. Gittleman, F. T. Van Manen, and M. J. Chamberlain. 2017. Using diets of Canis breeding pairs to assess resource partitioning between sympatric red wolves and coyotes. Journal of Mammalogy 98:475-488.

Honda, T., H. Iijima, J. Tsuboi, and K. Uchida. 2018. A review of urban wildlife management from the animal personality perspective: The case of urban deer. Science of the Total Environment 644:576-582.

Huegel, C. N., and O. J. Rongstad. 1985. Winter foraging patterns and consumption rates of northern Wisconsin coyotes. American Midland Naturalist 113:203-207.

Jackson, A. M., and S. S. Ditchkoff. 2013. Survival estimates of white-tailed deer fawns at Fort Rucker, Alabama. American Midland Naturalist 170:184-190.

Jones, B. M., M. V. Cove, M. A. Lashley, and V. L. Jackson. 2016. Do coyotes Canis latrans influence occupancy of prey in suburban forest fragments? Current Zoology 62:1–6.

Kavaliers, M. and E. Choleris. 2001. Antipredator responses and defensive behavior: ecological and ethological approaches for the neurosciences. Neuroscience & Biobehavioral Reviews 25:577–586.

Kilgo, J. C., M. Vukovich, H. S. Ray, C. E. Shaw, and C. Ruth. 2014. Coyote removal, understory cover, and survival of white-tailed deer neonates. Journal of Wildlife Management 78:1261-1271.

Kilpatrick, H. J., A. M. Labone, and J. S. Barclay. 2007. Acceptance of deer management strategies by suburban homeowners and bowhunters. Journal of Wildlife Management 71:2095-2101.

Kilpatrick, H.J., and K. K. Lima. 1999. Effects of archery hunting on movement and activity of female white-tailed deer in an urban landscape. Wildlife Society Bulletin 27:433-440.

Kilpatrick, H. J., and S. M. Spohr. 2000. Spatial and temporal use of a suburban landscape by female white-tailed deer. Wildlife Society Bulletin 28:1023-1029.

Kilpatrick, H. J., S. M. Spohr, and K. K. Lima. 2001. Effects of population reduction on home ranges of female white-tailed deer at high densities. Canadian Journal of Zoology 79:949-954.

Klein, C., S. Barua, S. Liccioli, and A. Massolo. 2019. Neospora caninum DNA in coyote fecal samples collected in an urban environment. Journal of Wildlife Diseases 55:196-199.

Larson, R. N., D. J. Morin, I. A. Wierzbowska, and K. R. Crooks. 2015. Food habits of coyotes, gray foxes, and bobcats in a coastal southern California urban landscape. Western North American Naturalist 26:1520-1527.

Lashley, M. A., M. C. Chitwood, M. T. Biggerstaff, D. L. Morina, C. E. Moorman, and C. S. DePerno. 2014. White-tailed deer vigilance: The influence of social and environmental factors. PLoS ONE 9(3):e90652.

Laundré, J. W., L. Hernández, and W. J. Ripple. 2010. The landscape of fear: Ecological implications of being afraid. The Open Ecology Journal 3:1-7.

Liccioli, S., C. Bialowas, K. E. Ruckstuhl, and A. Massolo. 2015. Feeding ecology informas parasite epidemiology: prey selection modulates encounter rate with Echinococcus multilocularis in urban coyotes. PLoS ONE 10:e0121646.

Lima, S. L. 1998. Nonlethal Effects in the Ecology of Predator-Prey Interactions. BioScience 48:25–34.

Lingle, S. 2000. Seasonal variation in coyote feeding and mortality of white-tailed deer and mule deer. 2000. Canadian Journal of Zoology 78:85-99.

Lingle, S. 2001. Anti-predator strategies and grouping patterns in white-tailed deer and mule deer. Ethology 107:295-314.

Lingle, S., and W. F. Wilson. 2001. Detection and avoidance of predators in white-tailed deer (Odocoileus virginianus) and mule deer (O. hemionus). Ethology 107:125-147.

Lombardi, J. V., C. E. Comer, D. G. Scognamillo, and W. C. Conway. 2017. Coyote, fox, and bobcat response to anthropogenic and natural landscape features in a small urban area. Urban Ecosystems 20:1239-1248.

Long, R. A., A. F. O'Connell Jr., and D. J. Harrison. 1998. Mortality and survival of white-tailed deer Odocoileus virginianus fawns on a north Atlantic coastal island. Wildlife Biology 4:237-247.

MacCracken, J. G., and D. W., Uresh. 1984. Coyote foods in the Black Hills, South Dakota. The Journal of Wildlife Management 48:1420–1423.

Magle, S. B., L. S. Simoni, E. W. Lehrer, and J. S. Brown. 2014. Urban predator–prey association: coyote and deer distributions in the Chicago metropolitan area. Urban Ecosystems 17:875–891.

McCance, E. C., R. K. Baydeck, D. J. Walker, and D. N. Leask. 2015. Spatial and temporal analysis of factors associated with urban deer-vehicle collisions. Human-Wildlife Interactions 9:119-131.

McCance, E. C., M. M. Campbell, and R. K. Baydeck. 2015. White-tailed deer movement patterns in a Canadian metropolitan area. Human Dimensions of Wildlife 20:471-483.

McCoy, J. C., S. S. Ditchkoff, J. B. Raglin, B. A. Collier, and C. Ruth. 2013. Factors influencing survival of white-tailed deer fawn in coastal South Carolina. Journal of Fish and Wildlife Management 4:280-289.

Messier, F., C., Barrette, and J., Huot. 1986. Coyote predation on a white-tailed deer population in southern Quebec. Canadian Journal of Zoology 64:1134–1136.

Messmer, T. A., S. M. George, and L. Cornicelli. 1997. Legal considerations regarding lethal and nonlethal approaches to managing urban deer. Wildlife Society Bulletin 25:424-429.

Mitchell, N., M. W. Strohbach, R. Pratt, W. C. Finn, and E. G. Strauss. 2015. Space use by resident and transient coyotes un an urban-rural landscape mosaic. Wildlife Research 42:461-469.

Moll, R. J., J. D. Cepek, P. D. Lorch, P. M. Dennis, T. Robison, J. J. Millspaugh, and R. A. Montgomery. 2018. Humans and urban development mediate the sympatry of competing carnivores. Urban Ecosystems 21:765-778.

Moratz, K. L., B. S. Gullikson, E. S. Michel, J. A. Jenks, D. M. Grove, and W. F. Jensen. 2018. Assessing factors affecting adult female white-tailed deer survival in the Northern Great Plains. Wildlife Research 45:679-684.

Morey, P. S., E. M. Gese, and S. D. Gehrt. 2007. Spatial and temporal variation in the diet of coyotes in the Chicago Metropolitan Area. The American Midland Naturalist 158:147–161.

Murray, M., A. Cembrowski, A. D. M. Latham, V. M. Lukasik, S. Pruss, and C. C. St. Clair. 2015. Greater consumption of protein-poor anthropogenic food by urban relative to rural coyotes increases diet breadth and potential for human-wildlife conflict. Ecography 38:1235-1242.

Murray, M. H., and C. C. St. Clair. 2017. Predictable features attract urban coyotes to residential yards. Journal of Wildlife Management 81:593-600.

Newsome, S. D., H. M. Garbe, E. C. Wilson, and S. D. Gehrt. 2015. Individual variation in anthropogenic resource use in an urban carnivore. Oecologia 178:115-128.

O’Gara, B. W., and R. B. Harris. 1988. Age and condition of deer killed by predators and coyotes. Journal of Wildlife Management 52:316-320.

Patterson, B. R., L. K. Benjamin, and F. Messier. 1998. Prey switching and feeding habits of eastern coyotes in relation to snowshoe hare and white-tailed deer densities. Canadian Journal of Zoology 76:1885-1897.

Patterson, B. R. and F. Messier. 2003. Age and condition of deer killed by coyotes in Nova Scotia. Canadian Journal of Zoology 81:1894-1898.

Patterson, B. R. and F. Messier. 2001. Social organization and space use of coyotes in eastern Canada relative to prey distribution and abundance. Journal of Mammalogy 82:463-477.

Petroelje, T. R., J. L. Belant, D. E. Beyer Jr., G. Wang, and B. D. Leopold. 2014. Population-level response of coyotes to a pulsed resource event. Population Ecology 56:349-358.

Piccolo, B.P., T.R. Van Deelen, K. Hollis-Etter, D.R. Etter, R.E. Warner, and C. Anchor. 2010. Behavior and survival of white-tailed deer neonates in two suburban forest preserves. Canadian Journal of Zoology 88:487–495.

Pierce, J. L. B., S. A. Dalinsky, A. Chenaille, L. M. Lolya, J. L. Maguder, C. Mattilio, G. V. Mayhew, E. Regan, and D. A. Patrick. 2015. Scale-dependent effects of coyote-predation risk on patterns of white-tailed deer browsing along linear forest edges. Northeastern Naturalist 22:262–272.

Poessel, S. A., S. W. Breck, and E. M. Gese. 2016. Spatial ecology of coyotes in the Denver metropolitan area: Influence of the urban matrix. Journal of Mammalogy 97:1414-1427.

Poessel, S. A., E. M. Gese, and J. K. Young. 2017. Environmental factors influencing the occurrence of coyotes and conflicts in urban areas. Landscape and Urban Planning 157:259-269.

Poessel, S. A., E. C. Mock, and S. W. Breck. 2017. Coyote (Canis latrans) diet in an urban environment: variation relative to pet conflicts housing density, and season. Canadian Journal of Zoology 95:287-297.

Porter, W. F., H. B. Underwood, and J. L. Woodard. 2004. Movement behavior, dispersal, and the potential for localized management of deer in a suburban environment. Journal of Wildlife Management 68:247-256.

Richardson, K. E. and F. W. Weckerly. 2007. Intersexual social behavior of urban white-tailed deer and its evolutionary implications. Canadian Journal of Zoology 85:759-766.

Rohm, J. H., C. K. Nielsen and A. Woolf. 2007. Survival of White-Tailed Deer Fawns in Southern Illinois. Journal of Wildlife Management 71:851–860.

Saalfeld S. T. and S. S. Ditchkoff. 2007. Survival of neonatal white-tailed deer in an exurban population. The Journal of Wildlife Management 71:940-944.

Santana, E., and J. Armstrong. 2017. Food habits and anthropogenic supplementation in coyote (Canis latrans) diets along an urban-rural gradient. Human-Wildlife Interactions 11:156-166.

Schrecengost, J. D., J. C. Kilgo, D. Mallard, H. S. Ray, and K. V. Miller. 2008. Seasonal food habits of the coyote in the South Carolina coastal plain. Southeastern Naturalist 7:135-144.

Schuttler, S. G., A. W. Parsons, T. D. Forrester, M. C. Baker, W. J. McShea, R. Costello, and R. Kays. 2017. Deer on the lookout: how hunting, hiking and coyotes affect white-tailed deer vigilance. Journal of Zoology 301:320-327.

Seamans, T. W., B. F. Blackwell, and J. D. Cepek. 2002. Coyote hair as an area repellent for white-tailed deer. International Journal of Pest Management, 48:4, 301-306.

Seamans, T. W., B. F. Blackwell, and K. E. Linnell. 2016. Use of predator hair to enhance perceived risk to white-tailed deer in a foraging context. Human-Wildlife Interactions 10:300-311.

Shuman, R. M., M. J. Cherry, T. N. Simoneaux, E. A. Dutoit, J. C. Kilgo, M. J. Chamberlain, and K. V. Miller. 2017. Survival of white-tailed deer neonates in Louisiana. Journal of Wildlife Management 81:834-845.

Storm, D. J., C. K. Nielsen, E. M. Schauber, and A. Woolf. 2007. Space use and survival of white-tailed deer in an exurban landscape. Journal of Wildlife Management 71:1170-1176.

Stout, R. J., R. C. Stedman, D. J. Decker, and B. A. Knuth. 1993. Perceptions of risk from deer-related vehicle accidents: implications for public preferences for deer herd size. Wildlife Society Bulletin 21:237-249.

Sutton, N. M. and E. J. Heske. 2017. Effects of human state park visitation rates on escape behavior of white-tailed deer. Human-Wildlife Interactions 11:86-98.

Swihart, R. K., P. M. Picone, A. J. DeNicola, and L. Cornicelli. 1995. Ecology of urban and suburban white-tailed deer. In: McAninch JB (ed) Urban deer: a manageable resource? 1993 Symposium of the North Central Section. The Wildlife Society, St. Louis, Missouri, USA pp 35-44.

Swihart, R. K., J. J. Pignatello, and M. J. I. Mattina. 1991. Aversive responses of white-tailed deer, Odocoileus virginianus, to predator urines. Journal of Chemical Ecology 17:767–777.

Telford, S. R., T. N., Mather, S. I., Moore, M. L., Wilson, and A., Spielman. 1988. Incompetence of deer as reservoirs of the Lyme disease spirochete. American Journal of Tropical Medicine and Hygiene 39:105–109.

Turner, M. M., A. P. Rockhill, C. S. Deperno, J. A. Jenks, R. W. Klaver, A. R. Jarding, T. W. Grovenburg, and K. H. Pollock. 2011. Evaluating the effect of predators on white-tailed deer: Movement and diet of coyotes. Journal of Wildlife Management 75:905-912.

Urbanek, R. E. and C. K. Nielsen. 2013. Influence of landscape factors on density of suburban white-tailed deer. Landscape and Urban Planning 114:28-36.

VerCauteren, K. C. 2003. The deer boom: Discussions on the population growth and range expansion of the white-tailed deer. USDA National Wildlife Research Center-Staff Publications 281.

VerCauteren, K. C., J. A. Shivik, and M. J. Lavelle. 2005. Efficacy of an animal-activated frightening device on urban elk and mule deer. Wildlife Society Bulletin 33:1282-1287.

Vreeland, J.K., D. R. Diefenbach, and B. D. Wallingford. 2004. Survival rates, mortality causes, and habitats of Pennsylvania white-tailed deer fawns. Wildlife Society Bulletin 32:542-553.

Waller, D. M., and W. S. Alverson. 1997. The white-tailed deer: a keystone herbivore. Wildlife Society Bulletin 25:217–226.

Walter, W. D., J. Beringer, L. P. Hansen, J. W. Fischer, J. J. Millspaugh, and K. C. VerCauteren. 2011. Factors affecting space use overlap by white-tailed deer in an urban landscape. International Journal of Geographical Information Science 25:379-392.

Walter, W. D., K. C. VerCauteren, H. Campa III, W. R. Clark, J. W. Fischer, S. E. Hygnstrom, N. E. Mathews, C. K. Nielsen, E. M. Schauber, T. R. Van Deelen, and S. R. Winterstein. 2009. Regional assessment on influence of landscape configuration and connectivity on range size of white-tailed deer. Landscape Ecology 24:1405-1420.

Ward, J. N., J. W. Hinton, K. L. Johannsen, M. L. Karlin, K. V. Miller, and M. J. Chamberlain. 2018. Home range size, vegetation density, and season influences prey use by coyotes (Canis latrans). PLoS ONE 13(10): e0203703.

Waser, N. M., M. V. Price, D. T. Blumstein, S. Reneé Arózqueta, B. D. Castro Escobar, R. Pickens, and A. Pistoia. 2014. Coyotes, deer, and wildflowers: diverse evidence points to a trophic cascade. Naturwissenschaften 101:427–436.

Way, J. G. 2007. Movements of transient coyotes, Canis latrans, in urbanized eastern Massachusetts. Canadian Field-Naturalist 121:364-369.

White, L. A., and S. D. Gehrt. 2009. Coyote attacks on humans in the United States and Canada. Human Dimensions of Wildlife 14:419-432.

Whitlaw, H. A., W. B. Ballard, D. L. Sabine, S. J. Young, R. A. Jenkins, and G. J. Forbes. 1998. Survival and cause-specific mortality rates of adult white-tailed deer in New Brunswick. Journal of Wildlife Management 62:1335-1341.

Whittaker, D. G., and F. G. Lindzey. 1999. Effect of coyote predation on early fawn survival in sympatric deer species. Wildlife Society Bulletin 27:256-262.

Chapter 2: White-tailed Deer Fawn Mortality in a Suburban Forest Preserve of Chicago

INTRODUCTION

Populations of white-tailed deer (*Odocoileus virginianus*) experience varying survival rates and causes of mortality across this species' range. For example, a study conducted in an exurban area of Illinois showed a survival rate of 0.87 for adult deer, with hunting being the primary cause of mortality (Storm et al. 2007). Another study conducted in rural British Columbia, however, shows a similar survival rate for adult deer (0.81), but with cougar predation as the main cause (Robinson et al. 2002). Survival rates and mortality causes may also differ among age classes within a population. An example of survival rate and mortality cause discrepancy between age classes is seen in South Carolina where studies have been conducted on both adult and fawn white-tailed deer. According to these studies, adult white-tailed deer had a survival rate of 0.87, with hunting accounting for majority of mortalities (Kilgo et al. 2016) and fawns at the same site had a survival rate of 0.23, with coyote (*Canis latrans*) predation as the most common cause of mortality (Kilgo et al. 2012). Survival rates and mortality causes for deer neonates are dependent on a variety of factors, including location, habitat, human-related disturbance, deer density, and predator densities (Gingery et al. 2018).

In the Chicago region, adult white-tailed deer are rarely depredated by coyotes (Etter et al. 2002). A coyote diet analysis, conducted in multiple suburban Chicago forest preserves, revealed white-tailed deer as an important food source (22% occurrence in all coyote scats collected); the authors believed that majority of deer remains found in scat were of fawns and carrion (Morey et al. 2007). White-tailed deer fawns are known to be commonly hunted and consumed by coyotes in the Chicago region. A fawn mortality study conducted from 1999-2001 in two suburban forest preserves of Chicago found that fawn mortality differed between the two study sites, with one location experiencing 72% mortality and the other 27%. Coyote predation accounted for the majority of fawn deaths at both sites (Piccolo et al. 2010).

The objective of our study was to determine the survival rate and causes of mortality of white-tailed deer fawns within an urban forest fragment. Previous fawn mortality data for the study area is also included to determine the presence of mortality-related patterns in the study sites and to discern whether the time during which the behavior study took place had similar survival rates as previous years. Because of the high coyote densities at our study site, we predicted a low average white-tailed deer fawn survival rate and high incidents of coyote predation.

METHODS

Study Area

Fieldwork was conducted in the Chicago metropolitan area located in northeast Illinois. With a temperate climate, summer temperatures reach an average of 27°C and winter temperatures fall to an average of -7.7°C. Average rainfall for this area is 99.1 cm per year (United States Climate Data, 2018).

The city of Chicago is located in the county of Cook. The eastern edge of the county borders Lake Michigan, with the city of Chicago located centrally along this edge. Cook County had an estimated human population of over 5.2 million in 2017 (United States Census Bureau, 2018), and the vast majority of the land in Cook County was urban and suburban, with greenspaces distributed throughout. The greenspaces, however, tended to be larger further from the city center. The majority of greenspace in Cook County was owned and managed by the Forest Preserves of Cook County which manages over 27,900 ha.

Our work was conducted at the Poplar Creek Forest Preserve in the western suburbs of Chicago and the northwest corner of Cook County. Owned and managed by the Forest Preserves of Cook County, the 1,825 ha Poplar Creek Forest Preserve is ~50 km from the Chicago city center. Habitats within this preserve included old fields, agricultural areas, forests, prairie, open water, and a few picnic areas with paved roads and parking lots. A medium-density housing development, a commercial area, and an 8-lane highway (I-90) bordered this preserve. Poplar Creek was chosen for our study because of the high white-tailed deer and coyote densities (>23 deer/km^2 (Piccolo et al. 2010); 5–10 coyotes/km^2 (Gehrt et al. 2011)) and to expand on previous and concurrent research conducted in this area.

Within the Poplar Creek Forest Preserve, we used 3 study blocks that were bordered by roads. Blocks 1, 2, and 3 were chosen within the study area due to the availability of capture sites, known inhabitance by study animals (both deer and coyotes), diversity of land use, and varying human presence. Block 1 was the largest of the study blocks, containing 446.4 ha. Located in the northeastern portion of Poplar Creek, block 1 was made up of forested land, prairie, small ponds, marshland, agricultural fields, recreational areas, and two office buildings. The recreational areas of block 1 included a model airplane field along the northern border and a picnic grove and bike path along the eastern border. The office buildings were situated along the southern edge of the block. These offices were used by the Forest Preserves of Cook County's Law Enforcement Department and Wildlife Management Division. Also located within this block was an open carcass pit used by the Forest Preserves' Wildlife Management Division to dispose of culled animals in association with management activities. The carcass pit was believed to be an attractant to coyotes in the area, possibly yielding higher coyote densities in block 1. There was potential for incidents of coyote predation of fawns to be higher within this block because of the higher coyote densities.

Block 2 was located in the southwestern section of Poplar Creek, comprising of 314.8 ha of land. This block consisted primarily of forested land and prairie, with a creek and some marsh areas and ephemeral ponds. Block 2 also included a loop trail that is often used by hikers, runners, dog walkers, cross country skiers, and equestrian riders. A railroad ran along the western edge of this block. A residential area was located directly west of this railroad.

Block 3 was located north of block 2, with a state route between them. Block 3 consisted of 232.8 ha and was the smallest of the study sites. This block consisted of primarily forests and both restored and remnant prairies. Block 3 also had a creek that runs along the southern portion and a pond in the center. Similar to block 2, block 3 had a railroad along its western edge and residential properties on the opposite side of that railroad. In addition, block 3 had a picnic grove and a bike path along the eastern edge and a trail system throughout the block. This trail was frequented by hikers, joggers, bicyclists, dog walkers, and cross-country skiers.

Visitors were encouraged via signage at the site to stay along trails at each of these sites. However, off-trail hikers were often encountered. The Forest Preserve enforces through ticketing that dogs must remain leashed on their properties, but off-leashed dogs were commonly seen.

Blocks 2 and 3, and block 1 to some extent, experienced land restoration practices throughout most of the year. Hunting was prohibited on all Forest Preserve property. Although deer culling was used as a management method in some preserves in other areas of Cook County, culling did not occur in Poplar Creek due to the ongoing white-tailed deer study.

The fawn mortality study was conducted in Poplar Creek to expand on former and current research projects on the white-tailed deer and coyote populations at this site. Using this site also allowed our team to acquire study fawns from collared does captured in previous years. We include fawn mortality data from 2013-2016 in our study to gain a better understanding of the predator-prey relationship in this area. Although most of the study fawns during those years occurred in our designated study blocks, 2 fawns were caught in areas within Poplar Creek directly adjacent to block 1. The landscape of these capture locations is similar to those of the study blocks used in our research. We chose to include these two fawns in our study because we are interested in the depredation of fawns in Poplar Creek as a whole in addition to each study block.

Doe Capture

The wildlife biologists of the Forest Preserves of Cook County conducted all white-tailed deer trapping and processing in accordance with the District's deer management program. Capturing and handling procedures of deer followed the guidelines of the American Society of Mammalogists (Sikes 2016). White-tailed deer does were captured from November to March during 2013 through 2018. Trapping took place in the morning and evening. This trapping schedule offered the greatest opportunity of capture as these times of day are when deer were most active. Drop nets, rocket nets, and darts with chemical immobilization fired from the ground were used to capture deer. Processing methods for white-tailed deer most closely followed those used by Etter et al. (2002). Captured white-tailed deer were immobilized with xylazine hydrochloride and Telozol (Zoetis Services, Parsippany, NJ, USA). After immobilization, white-tailed deer were fitted with very high frequency (VHF) collars (ATS M2510B; Advanced Telemetry Systems, Inc., Isanti, MN, USA). Adult does (>1.5 yr) were also fitted with vaginal implant transmitters (VIT) (ATS M3900; Advanced Telemetry Systems, Inc., Isanti, MN, USA) to assist with capture of fawns in the spring and early summer. VITs were designed to remain in the vaginal canal of a doe until parturition. After the VIT is expelled, the change in temperature detected by the VIT results in a change in pulse rate, thereby notifying a birthing event. We used the methods described by Carstensen et al. (2003) for VIT implantation. After does were collared and received a VIT, the effects of the immobilization were chemically reversed with the administration of yohimbine hydrochloride, and the does were released.

Doe Monitoring

Locations of does were collected 1–2 times a week outside of the fawn birthing and rearing season (August–April). Doe locations were collected through the use of triangulation from a vehicle with a 4-element fixed Yagi antenna mounted on the roof. During location collection in the spring, the VHF beacon of each does' VIT was checked to verify that the VIT was still with the doe and functioning properly. This protocol continued until the birthing season.

White-tailed deer does tend to give birth from May to mid-July (Nixon et al. 1991). Starting in early May, does were located 4–5 times a week (2–3 day locations and 2 night locations). VIT frequencies were checked 3–4 times a day for changes in pulse rate to determine whether a birthing event occurred.

Starting in June during our study years, 3–4 locations were collected each week for collared deer, including fawns. This schedule of location collection continued through July, when does are rearing fawns and when those fawns are most susceptible to predation (Cook et al. 1971, Nelson and Woolf 1987, Rohm et al. 2007, Grovenburg et al. 2011). Doe location collection decreased to once a week in August and continued until May of the following year.

Fawn Capture

Fawn capture and processing was conducted by the Forest Preserves of Cook County wildlife biologists as part of the district's deer management program. Fawns were found using 3 methods: VITs, collared doe searches, and systematic searches. With the assistance of VITs, fawns were located after parturition. During the birthing process, the VIT is expelled from the doe, and the internal temperature gauge in the VIT detects a decrease in temperature. The change in temperature reading causes the VHF beacon emitted from the VIT to change. Personnel used the preprogramed PET coding of the VIT to determine when that birthing event occurred. The altered beacon begins when the VIT temperature falls below 32 °C, indicating that the VIT has been expelled. Beacons from the VITs were checked 3–4 times a day during the fawning season until all VITs were dropped. Fawns were captured by hand after the detection of the birthing beacon emitted by the VIT. Before beginning fawn searches, the team waited a minimum of three hours after the birthing beacon began to allow time for grooming and doe-fawn bonding. If a fawn was not found at the birthing site with its VIT, the team searched a 200–400m radius around the site where the VIT was found (Carstensen et al. 2003). If the team failed to find a fawn, research personnel walked in on the doe the next day to search the surrounding area near the doe.

Many of the does included in our study were trapped in years prior and, therefore, were not fitted with VITs for fawn seasons after their capture year. Our team conducted area searches surrounding these does during the fawn season to look for their fawns. The VHF collars on these does were used to locate does and try to observe their behavior. Does with fawns typically stay within the area and vocalize when disturbed (Carstensen et al. 2003). If the doe was showing behavior that was indicative of fawn presence, the team searched the surrounding area where the doe was first seen. If a fawn was not found, the team conducted another search for fawns on a separate date. Area searches occurred a minimum of four days apart to limit stress on the doe.

Systematic searches were also conducted to locate fawns. Searches were conducted with a minimum of 4 researchers walking in a line through the study site. Each researcher walked no more than 10 m away from each other to leave little room for a fawn to remain unseen during the search. The team also walked at a slow pace to make sure that the area was properly searched and that no fawns were missed. Systematic searches were conducted in potential fawn bedding areas based on where deer had previously been spotted and where fawns had been captured in previous years.

Our capture and processing protocols followed those of Piccolo et al. (2010) and the guidelines of the American Society of Mammalogists (Sikes 2016). Detected fawns were carefully captured by hand and held away from the researchers' body to limit scent transmission. Each fawn was weighed, aged, and fitted with an expandable VHF collar (Advanced Telemetry Systems, Isanti, MN). Weight was determined by placing the fawn in a cotton bag and using a hand scale. Fawns were aged by examining their umbilicus condition and hoof growth (Haugen and Speake 1958; Sams et al. 1996; Brinkman et al. 2004). Fawn behavior was recorded and assessed on a scale ranging from 1 (still when approached, calm during handling, and quiet) to 5 (ran when approached, struggled during handling, and bleating). GPS locations and surrounding habitat were also recorded. To minimize scent contamination, all equipment used during processing was brought into the field in a storage container used only for fawn handling materials. When equipment was not in use, all materials were stored with natural plant material. For our study, cedar bows were used to prevent scent contamination because cedar is commonly found in the study area and is strongly scented. All personnel handling fawns wore nitrile gloves and rubber boots to avoid transmitting human scent onto the fawns and the immediate area surrounding the fawns. Personnel also attempted to limit duration of handling fawns to ≤ 3 minutes.

Fawn Monitoring

Telemetry and mortality determination techniques followed those described by Piccolo et al. (2010). We located marked fawns at least 3 times a day in the first 8 weeks. Frequent beacon checking allowed our team a greater chance of determining a cause of death. After 8 weeks, the chance of predation reduces significantly, so fawn checks dropped to 2–3 times per week. Fawn locations were also obtained 3–4 times a week during June and July via triangulation. We conducted triangulation through the use of a 4-element fixed Yagi antenna mounted on a truck. This allowed the team to determine fawn locations and check for mortality effectively and efficiently. If a mortality beacon was detected, searches took place to locate the transmitter and determine the cause of the fawn's death.

We identified cause of death by visible wounds on the carcass, state of the collar and its immediate area, location of the collar, and other external evidence. Coyote kills are identified by tooth punctures and consumption patterns, placement of remains (i.e. cached), and any evidence left behind such as scat and tracks (White 1973). All retrieved collar locations were recorded. If the carcass remained intact and cause of death could not be determined, the carcass was sent for necropsy by the Brookfield Zoo's Zoological Pathology Program. In cases where there were no signs of predation but the collar was found off of the fawn, we assumed that the collar slipped off and that the fate of the fawn could not be determined. Slipped collars most frequently occurred >6 months after collar deployment, and the collars were often found expanded and frayed suggesting that the loosened collar fell off the deer.

Mortality Analysis

We estimated survival rate through the Kaplan-Meier method by using the survival package in R. Survival rates were calculated for each year of the behavioral study (2017–2018), as well as each year and the entire duration of the fawn survival study (2013–2018). Rates of survival were also calculated and compared for each sex and study block. In order to determine which factors are most influential for fawn mortality we used Cox-proportional hazards survival model. We then developed a model set that included covariates of potential significance. This model set included sex, fawn behavior, capture weight, estimated birth mass (capture weight – (estimated age in days * 0.2kg)) (Verme and Ullrey 1984, Rawson et al. 1992, Carstensen et al. 2009), capture habitat, year, and capture location (block 1, block 2, block 3, or Other). We used Akaike's Information Criterion adjusted for small sample size for model selection.

Predation-caused mortality was compared between years, sexes, age classes, and capture locations. We also explored what factors in our study influenced coyote depredation of fawns by the creation of a model set that included covariates of potential importance. This model set included age class at death, sex, year, capture behavior, capture weight, estimated birth mass, capture habitat, and capture location. The covariate “age class at death” included four age categories that were separated by important developmental and behavioral stages in the first year of a deer’s life (0–2 weeks, 2–4 weeks, 4–8 weeks, >8 weeks (Nelson and Woolf 1987, Rohm et al. 2007, Grovenburg et al. 2012)). These covariates were investigated individually as well as in combinations that had potential to be significant.

We predicted the age class of a fawn to be influential to the survival rate and associated with predation because of increased vulnerability to predation in the first 2 weeks of life as a result of fawns primarily hiding during the day. Therefore, we truncated our data to the ages that had previously been reported to be significant in the survival of the first year of life. These ages are two weeks, eight weeks, and 1 year (Nelson and Woolf 1987, Rohm et al. 2007, Grovenburg et al. 2012). We also truncated our data at four weeks of age to further discern mortality factors. We then estimated mortality and coyote predation at each of these stages. All predictor variables in the models previously mentioned were used with the exception of the age class at death for the coyote predation model set.

RESULTS

During the 2016–2017 and 2017–2018 white-tailed deer trapping seasons, 12 does were captured and collared (5 in 2016–2017, 7 in 2017–2018). All does received VITs with the exception of one that was too active for safe implantation. VITs were monitored until expulsion or death.

During the 2017 and 2018 fawning seasons, which coincided with the other parts of the antipredator behavior study, 28 fawns were captured (14 in 2017, 14 in 2018). Eleven of these fawns were the offspring of our collared deer. Total fawn captures, including the 2017 and 2018 seasons, for the concurrent fawn survival study were 81 fawns (14 in 2013, 15 in 2014, 16 in 2015, 8 in 2016). Of the captured fawns, 39 were males and 42 were females. Of the total sample, there were 11 sets of twins and 4 sets of triplets. One of the sets of triplets, however, included 1 live fawn and 2 stillborn fawns. Only the live fawn was included in the study. Fourteen fawns were captured in block 1 (4 in 2017, 1 in 2018), 60 were captured in block 2 (6 in 2017, 12 in 2018), 5 were captured in block 3 (4 in 2017, 1 in 2018), and 2 were captured in areas adjacent to the 3 study blocks (Figure 2.1).

There were 20 mortalities from the 28 fawns captured during the 2017 and 2018 fawning seasons (8 mortalities in 2017, 12 mortalities in 2018). The survival rate was 0.43 (95% CI 0.23–0.79) in 2017 and 0.14 (95% CI 0.04–0.52) in 2018. In 2017, 3 of the 8 mortalities were males and the other 5 were females (male mortality = 42.9%, female mortality =71.4%). In contrast, 7 of the 12 mortalities in 2018 were males and the other 5 were females (male mortality = 100.0%, female morality = 71.4%).

Of the 81 total fawns captured during 2013–2018, we documented 54 mortalities during the first year of life. Our monitoring, concluded before the 2019 birthing season, so we, therefore, cannot be certain that the fawns of the 2018 season that survived to 8 months (n=2) survived their first year. The overall survival rate was 0.33 (95% CI 0.24–0.45) over the course of this study (Figure 2.2). Twenty-nine mortalities were male and 25 were female. Although the number of males and females captured were close to even (49.3% of captures were male, 50.7%

of captures were female), the survival differed between males and females. The survival rate for female fawns in our study was 0.41 (95% CI 0.28–0.58); whereas the survival rate for males in our study was 0.25 (95% CI 0.15–0.44). This difference, however, was not found to be significant ($p = 0.31$). Twenty-nine of the 54 mortalities were male (53.7%) and 25 were females (46.3%).

The survival rates in each of our study blocks varied. The survival rates for each block were 0.21 (95% CI 0.08–0.58) for block 1, 0.37 (95% CI 0.26–0.51) for block 2, and 0.4 (95% CI 0.14–1.0) for block 3. The survival rate for the fawns that were captured outside of the study blocks ($n=2$) was 0.0. The variation between these survival rates was not significant (log rank test: $p = 0.08$). The blocks with the lowest survival rates, however, were the sites closest to the Forest Preserve's carcass pit. When split by East (block 1 and other; sites closest to the carcass pit) and West side (blocks 2 and 3; sites furthest from the carcass pit), the difference in survival rates was significant ($p = 0.023$); East side survival rate of 0.19 (95% CI 0.07–0.52) and West side survival rate of 0.37 (95% CI 0.27–0.51).

Depredation accounted for the majority of mortalities ($n=42$, 77.8%). The other known cause of mortality for fawns was collision with vehicles ($n=3$, 5.6%). Fawns killed by a collision with a vehicle were only documented in 2015 ($n=1$) and 2018 ($n=2$). Nine (16.7%) of the mortalities were listed as having an unknown cause of mortality. The team could not confirm the cause of mortality for these fawns due to a lack of definite sign of depredation or vehicle collision. In the majority of these cases, a collar was found close to a road with or without some remnants of a fawn, but lacked distinct evidence whether the fawn was killed by coyote or scavenged after being hit by a vehicle. One of the mortalities listed as unknown was the result of a collar found in a residential backyard with a straight cut, indicating that the collar was cut off of the deer. In this case, poaching is a potential cause of death, but ultimately the cause is unknown.

For each year of our study, depredation by coyotes was the main cause of mortality. The proportion of coyote-caused deaths out of all deaths for a given year was highest in 2013 (n=10, 90.9% of mortalities) and lowest in 2014 (n=3, 60% of mortalities). The year with the highest number of coyote-caused mortalities, however, was in 2015 where 11 fawns were depredated by coyotes. In the years of our concurrent antipredator behavior study, coyote depredation accounted for 62.5% of fawn mortalities in 2017 and 75.0% in 2018. Coyotes killed 35.7% of all captured fawns in 2017 and 64.3% in 2018. Of the 81 fawns included in our study, 42 were killed by coyotes (51.9%). The average percentage of fawns killed by coyotes within the Poplar Creek Forest Preserve each year was 51.7% (95% CI 0.35–0.68).

The majority of the mortalities (n=30, 55.6%) occurred within the first 2 weeks of life for our study fawns (Table 2.1). The second age class, 2–4 weeks, experienced 15 mortalities (27.8% of all mortalities), resulting in the second highest amount of mortalities for age classes. The third and fourth age classes, 4–8 weeks and 8–52 weeks, had the lowest incidents of mortalities (n=4 and n=5, respectively), with 7.4% and 9.2% of all mortalities documented. As of the completion of our study, and not including the 2 surviving fawns of 2018, an average of 31.2% of the study fawns survived their first year of life.

When comparing the models in the first model set, which included factors that may have influenced the survival of the first year of life, the model containing year was best supported (Table 2.2). The two next best supporting models, however, had $\Delta AIC_C < 2$, suggesting that other factors had approximately equal weight in this data set. For the sets of models truncated at 2 weeks, 4 weeks, and 8 weeks, numerous models had $\Delta AIC_C < 2$. These models included sex, year, location, and weight at capture as predictor variables. The models that suggested that survival was constant were also highly ranked when compared to other models. With these results, it is difficult to determine whether the variables modeled here influenced fawn mortality significantly.

For the second model set, which included factors that could potentially influence whether mortality was caused by coyote depredation or other factors, the model containing only age class at death was best supported (Table 2.3). This supported our prediction that the age of a fawn has importance in potential causes of mortality (i.e. younger fawns are more susceptible to coyote predation). When truncated to the first 2 weeks, the model containing sex was best supported (Table 2.4). The models containing capture weight, habitat, and sex and capture weight, however, had $\Delta AIC_C < 2$, indicating that sex was not the best predictor in cause of mortality. When truncated at 4 weeks, the models containing habitat, weight at capture, and birth mass were best supported. In the first 8 weeks and the first year of life, the model containing location was best supported and all other models had $\Delta AIC_C > 2$. We acknowledge, however, that the limited amount of captures at two of our study blocks could potentially skew our data.

DISCUSSION

When comparing the survival rate of fawns in our study to the survival rate observed in other studies, our survival rate was lower than the average 0.41 survival rate attained from a meta-analysis of 37 white-tailed deer fawn survival publications (Gingery et al. 2018). The average yearly mortality for our study was 66.4% and within range of other fawn mortality studies in human dominated landscapes. This result falls between the observed mortality previously found in two other suburban Chicago forest preserves (27% and 72%) (Piccolo et al. 2010). The similarity of these results helps corroborate our yearly and average survival rates observed throughout our study. Observed mortality for our study also fell near the 67% observed mortality of white-tailed deer neonates found in an exurban area of Alabama (Saalfeld and Ditchkoff 2007). White-tailed deer fawn mortality typically varies whether in urban or non-urban areas. For example, a study conducted in rural southern Illinois reported a fawn survival rate of 0.59 (Rohm et al. 2007), which was 78.8% greater than the survival rate found in our study. The variations between the survival rates of rural and urban populations, as well as the variations between different populations within each of these landscape types, serve as an example of the population-level differences in the ecology of white-tailed deer.

The average mortality for male fawns over the course of our study was greater than that of female fawns, with a 17.9% difference. Male fawns had a greater mortality than female fawns each year with the exception of one year, 2017. This may give some evidence that the risk of mortality is greater for males than females early in life in the Chicago region, however this difference was found to not be significant. Other fawn mortality studies, however, vary with their male and female mortality ratios and an overall pattern has not been observed across this species' range (greater male survival: McCoy et al. 2013, Shuman et al 2017; greater female survival: Jackson et al. 1972, Carstensen et al 2009).

As predicted, coyote predation accounted for the majority of mortalities (77.8%) in our study. We expected coyote predation to be responsible for the majority of mortalities in our study because of the high density coyote population in our study area and the lack of other predators in the region. This finding is similar to the other suburban Chicago fawn mortality study, in which coyote predation accounted for 50% and 86% of mortalities at the two studied forest preserve sites (Piccolo et al. 2010). In the exurban Alabama study, coyote predation was the primary cause of mortalities as well, with 41.7% of mortalities (Saalfeld and Ditchkoff 2007). These studies suggest that coyotes can serve as a major source of fawn mortality in human-dominated landscapes. Through the predation of fawns, coyotes may limit deer population growth in these areas.

We cannot conclusively determine that coyotes are the main urban predator of white-tailed deer fawns in all urban areas due to the limited amount of research conducted within these areas. This is especially true given that the human-dominated landscapes used in previous studies lacked other potential predators that may serve a greater risk to fawn survival. In some non-urban studies, other predators were found to cause more mortalities than coyotes (e.g. black bears (Shuman et al. 2017)). Therefore, when present, other predators could influence mortality to urban deer greater then coyotes.

As described by Chitwood et al. (2017), opportunistic searches as a capture method for fawn mortality studies can lead to overestimated fawn survival rates and coyote predation as a cause of mortality. With the opportunistic search method, fawns that have died within the first 24 hours due to starvation from abandonment are likely not to be recorded and survival rates observed may be higher than what is actually occurring in the population. If starvation, which most often occurs early in life, is not accurately recorded as a cause of mortality, then an overemphasis on coyote predation-related fawn mortalities would occur.

A surprising result of our study was the lack of mortalities caused by domestic dogs. Although unleashed dogs are prohibited in our study area, dogs were often observed off-leash throughout the year in blocks 2 and 3. The other suburban Chicago forest preserve study found that dogs accounted for 14% and 17% of fawn mortalities at the two forest preserve study sites. Unlike Piccolo et al. (2010), our suburban forest preserve study did not attribute any mortalities conclusively to domestic canids. One potential explanation for this is that roads, a railroad, and a creek serve as boundaries between all residential areas and the forest preserve. These physical boundaries may limit unsupervised and unleashed dogs from accessing the preserve. Another explanation for a lack of dog kills in our sample could be attributed to a strong presence by research and management personnel in the study area. Often, when a walker with an unleashed dog was spotted, research crew members would confront the owner and remind them of the forest preserve leash requirement.

The small number of mortalities attributed to vehicle collisions (n=3) was also unexpected. Piccolo et al. (2010) found a limited number of mortalities caused by vehicle collisions (n=1), but we expected more incidents of vehicle collision deaths than observed. Our study area is surrounded and split by roads with speed limits up to 50 mph. We believed that these high speed roads would make avoiding deer more difficult. This, in addition to Etter et al.'s (2002) finding that vehicle collisions were the main cause of adult deer mortality in the Chicago region, led us to believe that more fawn mortalities would be attributed to collisions. A potential explanation for the low number of collision deaths could be due to does seldom crossing roads with young fawns. A small portion of our study fawns were observed to have crossed roads prior to 6 months of age (n=11). This tendency for does to stay within their birthing block may limit fawn collisions with vehicles. Another explanation for the limited number of observed vehicle-collision deaths could be due to coyotes scavenging hit fawns and leading us to categorize the cause of mortality as unknown.

Majority of the mortalities in our study occurred in the first two weeks after birth (n=30, 55.6%) and mortality numbers declined after those first weeks. This pattern has been observed in numerous other fawn mortality studies where coyote predation is a major source of mortality (e.g. Long et al. 1998, Ballard et al. 1999, Grovenburg et al. 2011, Shuman et al. 2017). In studies where other predators or vehicle collisions cause a majority of the mortalities, this pattern was not always observed (e.g. Kennedy 2015, Carstensen et al. 2009). This supports previous reports and our prediction that coyotes serve as the greatest threat to very young fawn survival in the Chicago region. Our findings support that coyote presence would impact deer behavior greatest when young fawns (≤2 months) are present. The results of our study, in conjunction with results of other fawn mortality studies, lends support to the idea that in areas where coyote predation is the main source of fawn mortality, majority of those mortalities will occur early in the fawns life while they are still in the “hiding stage” (0–2 weeks) and are therefore easier for coyotes to hunt.

MANAGEMENT IMPLICATIONS

As urbanization continues to grow, wildlife will continue to find means to live in these landscapes. By living in human-dominated landscapes, urban wildlife face unique challenges and situations that differ from their rural counterparts. Therefore, the relationships between urban wildlife species may present differently than in rural landscapes. Understanding how these urban dwelling species interact with each other and this landscape is crucial in making effective management decisions.

The survival rate observed in our study is likely of interest to deer managers in the Chicago region, as such information can assist in predicting how other factors including culling, disease emergence, and human disturbance might impact the population. These factors are of special concern when managing deer within an urban area that will likely come into contact with people in some way. As stated earlier, survival rates vary between locations and assumptions should not be made regarding mortality of a population. This is especially true when considering management actions such as hunting and culling. Hunting and culling quota are calculated through the use of recruitment rates which are influenced by mortality. Assumed survival rates of fawns, therefore, can greatly impact estimated recruitment and influence target hunting and culling numbers. Variation in fawn survival and cause-specific mortality between populations provide support for the examination of survival rates for every population of management interest.

Our results would be of interest to managers working in urban areas containing both deer and coyotes. Coyotes are a significant source of mortality to the white-tailed deer fawn population within our study area and can, therefore, also be a major influence in other areas as well. There is potential that coyotes play an important role in controlling deer populations within urban areas. Coyotes have spread rapidly across North America and into urban environments in recent decades (Ditchkoff et al. 2006, Gehrt 2007). How these predators influence other species is a common concern in areas where coyotes are relatively new. Any information on how coyotes impact other species is helpful in predicting and understanding how the arrival of this species will change the ecology in urban environments.

FIGURES AND TABLES

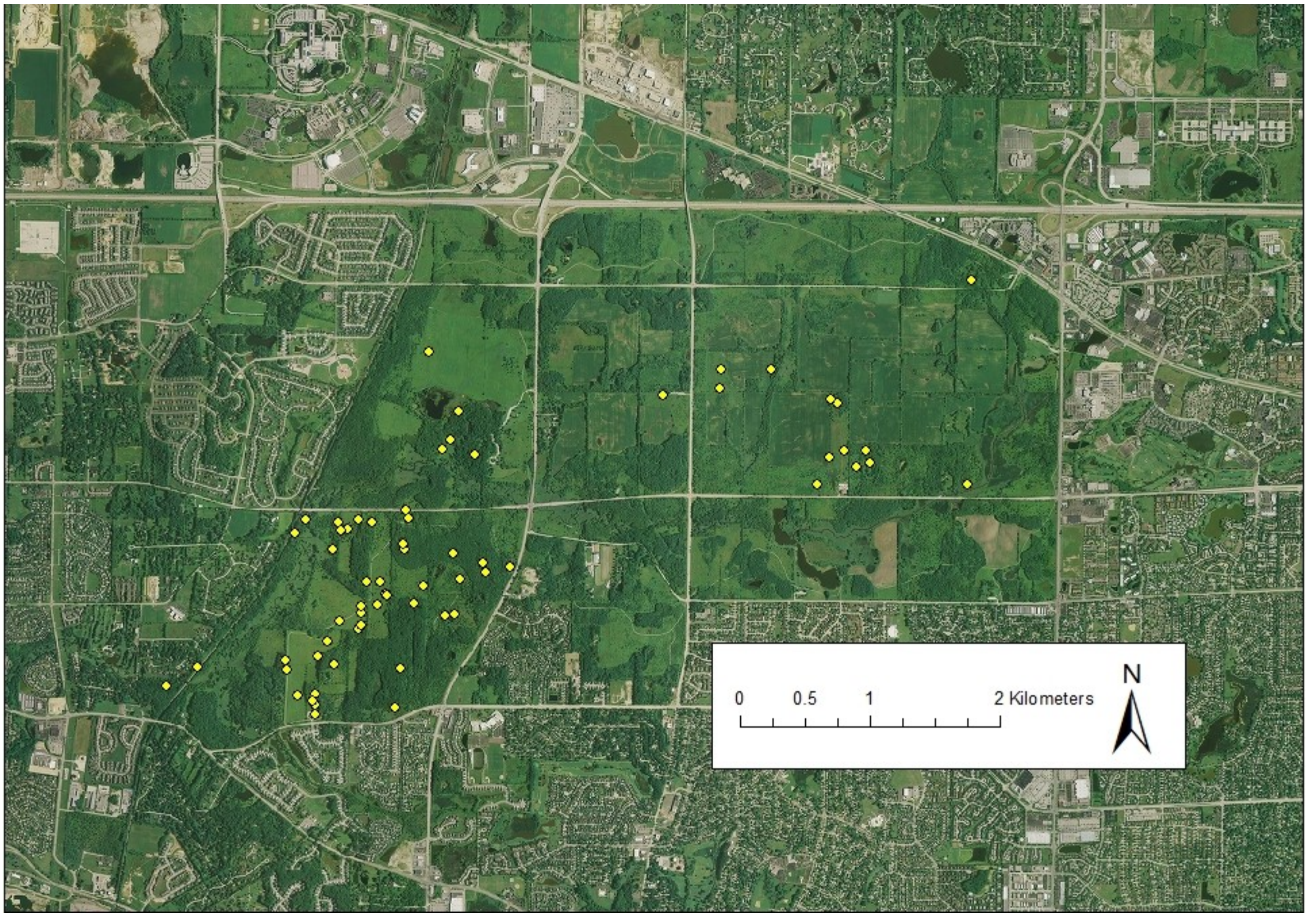

Figure 2.1: Map of white-tailed deer fawn capture locations from 2013–2018 in Poplar Creek Forest Preserve in Schaumburg and Hoffman Estates, IL.

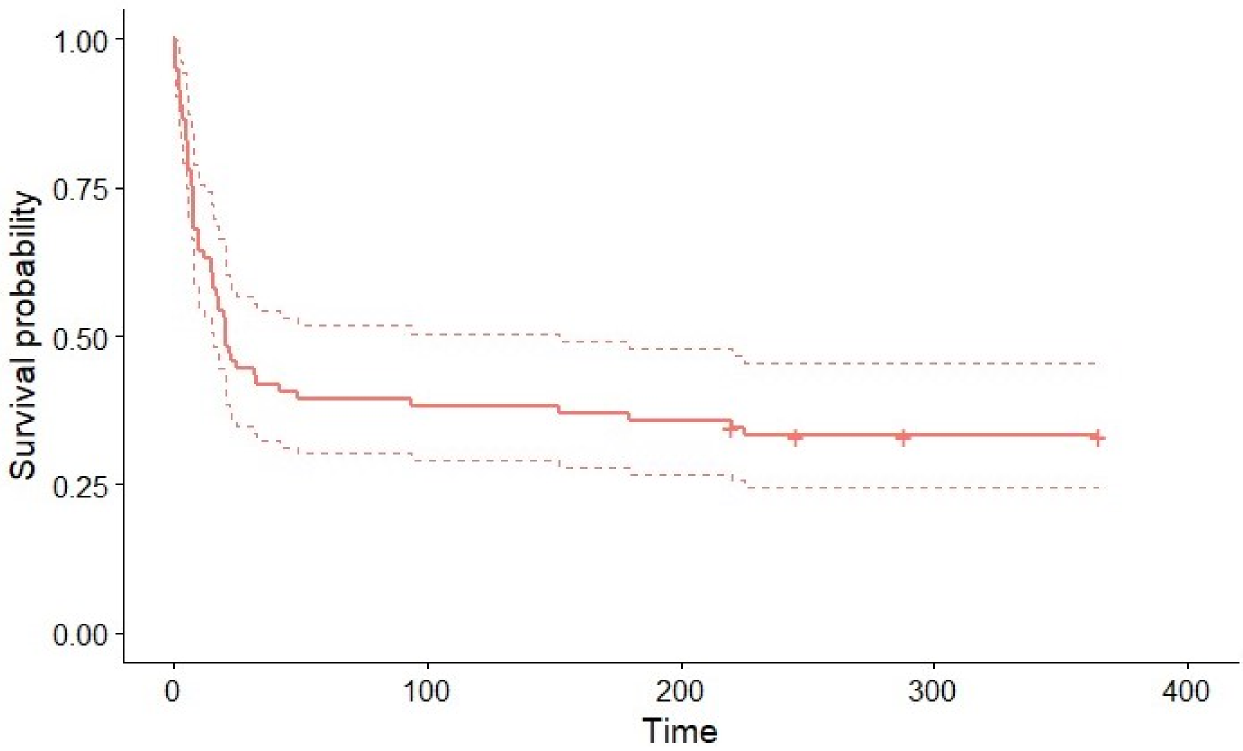

Figure 2.2: Kaplan-Meier survival curve for white-tailed deer fawns (n = 81) in Poplar Creek Forest Preserve, 2013–2018. This curve presents the average survival rate for fawns in this study. Time is the measure of days since birth.

Table 2.1: Fates of white-tailed deer fawns captured in Poplar Creek Forest Preserve, 2013–2018, including the sample size, number of mortalities, and number that survived the first year of life. Number of mortalities distributed between age classes each year is also shown here as well as totals for the entire study and averages for each year.

			Mortalities by Age Class					
Year	Sample Size	Mortalities	0–2 Weeks	2–4 Weeks	4–8 Weeks	>8 Weeks	Survived 1 Year	Proportion Survived
2013	14	11	8	3	0	0	3	0.21
2014	15	5	4	1	0	0	10	0.67
2015	16	13	5	5	1	2	3	0.19
2016	8	5	1	2	1	0	3	0.38
2017	14	8	6	0	2	0	6	0.43
2018	14	12	6	4	0	2	*	*
Total	81	54	30	15	4	4	25	1.88
Average	13.5	9.0	5.0	2.5	0.67	0.67	5.0	0.38

Table 2.2: Top model selection results investigating potential factors influencing survival for collared white-tailed deer fawns in 2013–2018 using Akaike's Information Criterion corrected for small sample sizes (AICc). This set was run for three distinct time periods of a fawn's life: the first 2 weeks, the first 4 weeks, the first 8 weeks, and the first year.

Survival of the first 2 weeks:

Model	AICc	ΔAICc	AICc Weight
$S_{constant}$	108.8333	0.0000	0.2173
$S_{location}$	109.4719	0.6385	0.1579
S_{sex}	109.6630	0.8296	0.1435
S_{WC}	110.4926	1.6592	0.0948
$S_{year+location}$	110.9234	2.0901	0.0764
S_{sex+WC}	111.4675	2.6342	0.0582

Survival of the first 4 weeks:

Model	AICc	ΔAICc	AICc Weight
$S_{\text{year+location}}$	112.3330	0.0000	0.2780
S_{location}	113.1927	0.8596	0.1809
S_{constant}	113.3384	1.0054	0.1682
S_{year}	114.4068	2.0738	0.0986
S_{sex}	115.4194	3.0863	0.0594
S_{WC}	115.5433	3.2103	0.0558

Survival of the first 8 weeks:

Model	AICc	ΔAICc	AICc Weight
S_{constant}	110.7459	0.0000	0.2673
S_{sex}	111.6448	0.8989	0.1487
S_{WC}	111.7778	1.0319	0.1467
S_{location}	112.3813	1.6354	0.1103
$S_{\text{sex+WC}}$	112.5027	1.7567	0.0605
S_{year}	113.6169	2.8710	0.0542

Survival of the first year of life:

Model	AICc	ΔAICc	AICc Weight
S_{year}	103.4110	0.0000	0.3417
S_{constant}	105.1659	1.7550	0.1421
S_{sex}	105.2480	1.8370	0.1364
$S_{\text{sex+WC}}$	106.9485	3.5375	0.0583
$S_{\text{year+location}}$	106.9506	3.5400	0.0582

Table 2.3: Results for top model selection for models involving factors with potential to influence whether fawn mortality is caused by coyote predation or by other causes in Poplar Creek Forest Preserve in Hoffman Estates, Illinois (2013–2018). Models were ranked using Akaike's Information Criterion corrected for small sample sizes (AICc). This model set includes the age class in which mortality occurred (DA).

Predation by coyotes:

Model	AICc	ΔAICc	AICc Weight
P_{DA}	45.8416	0.0000	0.5235
P_{DA+sex}	47.9956	2.1540	0.1783
$P_{DA+habitat}$	49.3294	3.4878	0.0915
P_{DA+BMC}	49.7625	3.9209	0.0737
P_{DA+WC}	50.4501	4.6085	0.0523
$P_{location}$	51.7491	5.9075	0.0273

Table 2.4: Results for top model selection for models involving factors with potential to influence whether fawn mortality is caused by coyote predation or by other causes at Poplar Creek Forest Preserve in Hoffman Estates, Illinois (2013–2018). Models were ranked using Akaike's Information Criterion corrected for small sample sizes (AICc). This model set excludes the age class in which mortality occurred (DA). This set was run for three distinct time periods of a fawn's life: the first 2 weeks, the first 4 weeks, the first 8 weeks, and the first year.

Death by predation in the first 2 weeks:

Model	AICc	ΔAICc	AICc Weight
P_{sex}	17.0024	0.0000	0.2731
P_{WC}	18.0855	1.0831	0.1589
$P_{habitat}$	18.2235	1.2211	0.1483
P_{WC+sex}	18.5974	1.5950	0.1230
$P_{BMC+sex}$	19.5054	2.5030	0.0781

Death by predation in the first 4 weeks:

Model	AICc	ΔAICc	AICc Weight
$P_{habitat}$	29.1690	0.0000	0.3021
P_{WC}	30.0105	0.8415	0.1983
P_{BMC}	30.1253	0.9563	0.1873
P_{sex}	31.2799	2.1109	0.1051
P_{WC+sex}	32.4251	3.2561	0.0593

Death by predation in the first 8 weeks:

Model	AICc	ΔAICc	AICc Weight
$P_{location}$	37.1042	0.0000	0.5668
P_{sex}	40.1759	3.0717	0.1220
P_{WC}	41.1023	3.9981	0.0768
$P_{habitat}$	41.4083	4.3041	0.0659
P_{BMC}	42.0151	4.9109	0.0486

Death by predation in the first year of life:

Model	AICc	ΔAICc	AICc Weight
$P_{location}$	51.7491	0.0000	0.5856
P_{BMC}	54.2344	2.4853	0.1690
P_{sex}	55.7881	4.0390	0.0777
$P_{BMC+sex}$	56.5499	4.8009	0.0531
$P_{habitat}$	56.8834	5.1343	0.0449

LITERATURE CITED

Ballard, W. B., H. A. Whitlaw, S. J. Young, R. A. Jenkins, and G. J. Forbes. 1999. Predation and survival of white-tailed deer fawns in northcentral New Brunswick. Journal of Wildlife Management 63:574-579.

Brinkman, T. J., K. L., Monteith, J. A. Jenks, and C. S., Deperno. 2004. Predicting neonatal age of white-tailed deer in the northern Great Plains. The Prairie Naturalist 36:75-81.

Carstensen, M., G. D. DelGiudice, and B. A., Sampson. 2003. Using doe behavior and vaginal-implant transmitters to capture neonate white-tailed deer in north-central Minnesota. Wildlife Society Bulletin 31:634–641.

Carstensen, M., G. D. DelGiudice, B. A. Sampson, and D. W. Kuehn. 2009. Survival, birth characteristics, and cause-specific mortality of white-tailed deer neonates. Journal of Wildlife Management 73:175-183.

Chitwood, M. C., M. A. Lashley, C. S. DePerno, and C. E. Moorman. 2017. Considerations on neonatal ungulate capture method: potential for bias in survival estimation and cause-specific mortality. Wildlife Biology 2017:wlb.00250.

Cook, R. S., M. White, D. O. Trainer, and W. C. Glazener. 1971. Mortality of young white-tailed deer fawns in south Texas. Journal of Wildlife Management 35:47-56.

Ditchkoff, S. S., S. T. Saalfeld, and C. J. Gibson. 2006. Animal behavior in urban ecosystems: Modifications due to human-induced stress. Urban Ecosystems 9:5–12.

Etter, D., K. Hollis, T. Van Deelen, D. Ludwig, J. Chelsvig, C. Anchor, and R. Warner. 2002. Survival and movements of white-tailed deer in suburban Chicago, Illinois. Journal of Wildlife Management 66:500-510.

Gehrt, S. D. 2007. Ecology of Coyotes in Urban Landscapes. Pages 303-311. Proceedings of the 12th Wildlife Damage Management Conference, Corpus Christi, Texas.

Gehrt, S. D., J. L. Brown, and C. Anchor. 2011. Is the urban coyote a misanthropic synanthrope? The case from Chicago. Cities and the Environment 4:Article 3.

Gingery T. M., D. R. Diefenbach, B. D. Wallingford, and C. S. Rosenberry. 2018. Landscape-level patterns in fawn survival across North America. Journal of Wildlife Management 82:1003-1013.

Grovenburg, T. W., R. W. Klaver, and J. A. Jenks. 2012. Survival of white-tailed deer fawns in the grasslands of the northern Great Plains. Journal of Wildlife Management 76:944-956.

Grovenburg, T. W., C. C. Swanson, C. N. Jacques, R. W. Klaver, T. J. Brinkman, B. M. Burris, C. S. Deperno, and J. A. Jenks. 2011. Survival of white-tailed deer neonates in Minnesota and South Dakota. Journal of Wildlife Management 75:213-220.

Haugen, A. O., and D. W. Speake. 1958. Determining age of young fawn white-tailed deer. Journal of Wildlife Management 22:319-320.

Jackson, R. M., M. White, and F. F. Knowlton. 1972. Activity patterns of young white-tailed deer fawns in south Texas. Ecology 53:262-270.

Kennedy, S. I. 2015. White-tailed deer (*Odocoileus virginianus*) fawn survival and seasonal patterns of white-tailed deer and coyotes (*Canis latrans*) in the Cleveland metropolitan area. Thesis, The Ohio State University, Columbus, USA.

Kilgo, J. C., H. S. Ray, M. Vukovich, M. J. Goode, and C. Ruth. 2012. Predation by coyotes on white-tailed deer neonates in South Carolina. Journal of Wildlife Management 76:1420–1430.

Kilgo, J. C., M. Vukovich, M. J. Conroy, H. S. Roy, and C. Ruth. 2016. Factors affecting survival of adult female white-tailed deer after coyote establishment in South Carolina. Wildlife Society Bulletin 40:747-753.

Long, R. A., A. F. O'Connell, and D. J. Harrison. 1998. Mortality and survival of white-tailed deer (*Odocoileus virginianus*) fawns on a north Atlantic coastal island. Wildlife Biology 4:237-247.

McCoy, J. C., S. S. Ditchkoff, J. B. Raglin, B. A. Collier, and C. Ruth. 2013. Factors influencing survival of white-tailed deer in coastal South Carolina. Journal of Fish and Wildlife Management 4:280-289.

Morey, P. S., E. M. Gese, and S. D. Gehrt. 2007. Spatial and temporal variation in the diet of coyotes in the Chicago Metropolitan Area. The American Midland Naturalist 158:147–161.

Nelson, T. A., and A. Woolf. 1987. Mortality of white-tailed deer fawns in southern Illinois. Journal of Wildlife Management 51:326-329.

Nixon, C. M., L. P. Hansen, P. A. Brewer, and J. E. Chelsvig. 1991. Ecology of white-tailed deer in an intensively farmed region of Illinois. Wildlife Monographs 118:3-77.

Piccolo, B. P., T. R. Van Deelen, K. Hollis-Etter, D. R. Etter, R. E. Warner, and C. Anchor. 2010. Behavior and survival of white-tailed deer neonates in two suburban forest preserves. Canadian Journal of Zoology 88:487–495.

Rawson, R. E., G. D. DelGiudice, H. E. Dziuk, and L. D. Mech. 1992. Energy metabolism and hematology of white-tailed deer fawns. Journal of Wildlife Diseases 28:91-94.

Robinson, H. S., R. B. Wielgus, and J. C. Gwilliam. 2002. Cougar predation and population growth of sympatric mule deer and white-tailed deer. Canadian Journal of Zoology 80:556–568.

Rohm, J. H., C. K. Nielsen and A. Woolf. 2007. Survival of white-tailed deer fawns in southern Illinois. Journal of Wildlife Management 71:851–860.

Saalfeld S. T. and S. S. Ditchkoff. 2007. Survival of neonatal white-tailed deer in an exurban population. The Journal of Wildlife Management 71:940-944.

Sams, M., R., Lochmiller, E., Hellgren, W., Warde, and L., Varner. 1996. Morphometric predictors of neonatal age for white-tailed deer. Wildlife Society Bulletin 24:53-57.

Shuman, R. M, M. J. Cherry, T. N. Simoneaux, E. A. Dutoit, J. C. Kilgo, M. J. Chamberlain, and K.V. Miller. 2017. Survival of white-tailed deer neonates in Louisiana. Journal of Wildlife Management 81:834-845.

Sikes, R. S. 2016. Guidelines of the American Society of Mammalogists for the use of wild mammals in research and education. Journal of Mammalogy 97:663-688.

Storm, D. J., C. K. Nielsen, E. M. Schauber, and A. Woolf. 2007. Space use and survival of white-tailed deer in an exurban landscape. The Journal of Wildlife Management, 71:1170–1176.

United States Census Bureau. 2018. Quick Facts: Cook County, Illinois. Retrieved from http://www.census.goc/quickfacts/fact/table/cookcountyillinois/PST120217.

United States Climate Data. 2018. Climate: Chicago-Illinois. Retrieved from https://www.usclimatedata.com/climate/chicago/illinois/united-states/usil0225.

Verme, L. J., and D. E. Ullrey. 1984. Physiology and nutrition. Pages 91-118 in L.K. Halls, editor. White-tailed deer ecology and management. Stackpole, Harrisburg, Pennsylvania, USA.

White, M. 1973. Description of remains of deer fawns killed by coyotes. Journal of Mammalogy 54:291-293.

Chapter 3: Seasonal Diet of Coyotes in a Suburban Forest Preserve of Chicago

INTRODUCTION

Coyotes (*Canis latrans*) are known to be opportunistic predators and scavengers (Morey et al. 2007). This feeding style allows coyotes to respond to changing food availability throughout the year (Crimmins et al. 2012). Previous research suggests that coyotes respond to the arrival of white-tailed deer (*Odocoileus virginianus*) fawns in the late spring and early summer by frequently consuming the neonates in areas where the two species coexist (Saalfeld and Ditchkoff 2007, Piccolo et al. 2010, Grovenburg et al. 2011, Kilgo et al. 2012, Shuman et al. 2017). This predation pattern is of great interest to our study because increased incidents of negative interaction are believed to provoke heightened antipredator behavior (Brown et al. 1999).

Urban coyotes are known primarily to consume small mammals, white-tailed deer, and vegetation (Cepek 2004, Morey et al. 2007, Lukasik and Alexander 2012, Poessel et al. 2017). In the Chicago region, coyotes are also known to consume anthropogenic resources, but do not seem to rely on these sources (Newsome et al. 2015). A previous diet analysis of coyotes in the Chicago region found the primary food source to be small rodents (Morey et al. 2007). White-tailed deer, eastern cottontail (*Sylvilagus floridanus*), and vegetation also were found to be important food sources for coyotes in the study area. Similar to other research, Morey et al.

(2007) found that the diet of coyotes in the Chicago region fluctuates seasonally with certain prey items consumed more frequently than others at different times of the year.

We decided to examine the diet of coyotes in our study site in conjunction with the concurrent behavioral research. Diet analyses can provide insight into not only what is consumed, but how that species might influence others through predation and competition (Klare et al. 2011). Information on coyote diet provides insight into how coyotes directly impact white-tailed deer and other prey populations at our study site. We intended to determine what the main food sources are for coyotes over the duration of our behavioral studies and whether white-tailed deer were an important food source for coyotes at the study site. To accomplish this, we collected coyote scat samples from the Poplar Creek Forest Preserve and conducted a diet analysis. For terrestrial carnivores, the most common technique of diet analysis is by the examination of scat (Klare et al. 2011). Morphological scat analysis is conducted by identifying undigested animal and plant matter. Hair, bones, teeth, feathers, hooves as well as other materials, often remain undigested and easily observable within coyote scats. Our main goal for our research was to determine how prevalent the remains of white-tailed deer were in scats at various times of the year and whether the presence of fawns in the area results in an influx of deer remains within coyote scats. We also aimed to examine the shifts in coyote diet throughout the year and determine if coyote diet followed increases in prey availability. We predicted that the remains of white-tailed deer would be most prevalent in coyote scats during the summer when fawns are most susceptible to coyote predation.

METHODS

Study Area

Coyote scats were collected from the Poplar Creek Forest Preserve in Hoffman Estates, Illinois. Poplar Creek was located in the northwest suburbs of Chicago. This site contained woodland, prairie, agricultural fields, wetlands, recreational areas, and trails. This preserve was intersected by roadways, railroad property, and residential areas. These boundaries split the preserve into blocks. We focused on three of these blocks as our study sites (block 1, block 2, and block 3). Scats were collected from each of the three study blocks. Chapter 2 describes these blocks, the overall study area, and the Chicago metropolitan area in further detail.

Scat Collection

Scats were collected at 3-month intervals in conjunction with the foraging behavior surveys from summer 2017 through summer 2018. This collection timeline insured collections for each season. We also lined up our collection of scats in the summer to occur after a majority of white-tailed deer does would have given birth, but before the fawns born early in the season would be 2-months old (mid-July). This confirms that fawns are present and that they are still within the age at which they are most vulnerable to coyote predation.

Research personnel walked down hiking and bike trails in the three study blocks and collected all coyote scats observed. We chose to sample scats from these paths because coyotes are known to deposit scat along well-travelled trails (Barrette and Messier 1980). These trails also offered a suitable method for traversing the study blocks. After all trails had been covered, personnel walked the paths again the next day until a minimum of 10 total scats were collected per block for that sampling period. A minimum of 30 scats were collected for each season (3 blocks × 10 scats (minimum) per block).

Scats were identified based on morphology. Typically, coyote scats are long with tapered ends (Cepek 2004). Coyote scat is easily discernable from dog scat, because the high grain diet of most dogs yields an excrement with a smoother appearance. Scats were not collected if their identification could not be confirmed.

Collected scats were each given an identification number and placed in a labelled Whirl-Pak bag (Nasco, Fort Atkinson, WI, USA). Collection date and a GPS location were also recorded for each scat. We categorized scats into four seasons: summer (July), fall (October), winter (January-February), and spring (April). Scats were stored in an ultra-low freezer at -80°C until analysis. By deep freezing the scats for a minimum of 72 hours, we eliminate the possibility of transmitting parasites, including *Echinococcus multilocularis* (Hildreth et al. 2004), to research personnel during analysis.

Scat Analysis

Samples were individually placed in two nylon stockings and washed in an automatic washing machine on gentle cycle without detergent. By washing the scats, residual matrix is removed and the remaining items are broken apart, making those components easier to identify. After washing, scats were air dried for a minimum of two days. Dried scats were individually broken apart and spread evenly on a lab tray for examination.

All non-hair items were identified and classified under the following categories: white-tailed deer, small mammals, eastern cottontail, raccoon (*Procyon lotor*), beaver (*Castor* *canadensis*), muskrat (*Ondatra zibethicus*), avian, invertebrate, herbaceous plant, fruit, human associated, or other. Hairs were sampled using a 2×5 line grid (10 intersections) placed on the sample tray. The guard hairs closest to each intersection were selected for identification (Mumma et al. 2016). Each individual guard hair was microscopically examined and compared to published keys on hair identification (Debelica and Thies 2009) and to our own reference collection from mammals of the area. Color and medulla patterns were used primarily for hair identification. Hairs were then categorized using the groups previously mentioned. The presence of white-tailed deer fawn remains was also recorded when small hooves were observed in the scat. Gravel and trace amounts of coyote hair were discarded from our analysis, because the gravel was likely incidentally collected and the hair ingested by the animal during grooming.

Frequency of occurrence per scat and frequency of occurrence per food item were calculated for our samples (Schrecengost et al. 2008, Swingen et al. 2015). Frequency of occurrence per scat is the percent of all samples that contain a particular item. Frequency of occurrence per item, however, is the number of times a particular food item occurs as a percent of all food items recorded. We compared these values between collection surveys to determine seasonal variations in the diet of coyotes of the Poplar Creek Forest Preserve. We used the frequency of occurrence of white-tailed deer remains to analyze the effect of season on deer consumption using analyses of variance (ANOVAs) and Tukey tests for multiple comparisons. Each of these tests were completed using Program R (R Development Team 2018). We also compared the calculated frequencies between study blocks to determine whether there were significant differences between coyote diets in each block.

RESULTS

One hundred and seventy-two coyote scats were collectively acquired from the three study blocks during the summer of 2017 through the summer of 2018. A total of 433 individual food items were identified from these scats. These items were classified into one of 12 categories described previously. Two hundred and thirty-six of these items were mammalian (54.5%), 91 were fruit (21.0%), 68 were herbaceous plants (15.7%), 19 were invertebrates (4.4%), 8 were avian (1.8%), 7 were human-associated (1.6%), and 4 were classified as other (0.9%).

Of the mammalian items classified, small mammals were the most prevalent (57.6%, Table 3.1). Observed small mammal items included the remains of voles (*Microtus* spp.), mice (*Peromyscus* spp.), squirrel (*Sciurus* spp.), thirteen-lined ground squirrel (*Ictidomys tridecemlineatus*), and northern short-tailed shrew (*Blarina brevicauda*). Thirteen-lined ground squirrel and short-tailed shrew remains were each found once and positively identified through jaw bones in the scat. Small mammal remains occurred most frequently in spring (80.6%) and least in the summer (35.5% in 2017; 41.9% in 2018). White-tailed deer remains were the second most common mammalian item, with a 53.5% frequency of occurrence. We found that the frequency of occurrence differed across seasons for white-tailed deer (F = 8.86, P = ≤ 0.001). Evidence of white-tailed deer consumption was highest in the summer (83.9% in 2017; 61.3% in 2018) and lowest in the winter (21.1%). Tukey tests revealed the same frequency of occurrence pattern. Of the scats collected from each block, the scats from block 1 had the highest occurrence of white-tailed deer remains for each season (Summer 2017 = 70.0%, Autumn 2017 = 50.0%, Winter 2018 = 46.2%, Spring 2018 = 50.0%, Summer 2018 = 60.0%). There was a substantial difference in occurrence between the scats of block 1, 2, and 3 in the winter (46.2%, 7.1%, and

8.1%, respectively). Positive identification of white-tailed deer fawn remains occurred in 8 of the 92 scats containing white-tailed deer remains. Rabbit remains were found in 17.4% of scats and were most often found in scats collected during the winter (42.1%). Muskrat, beaver, and raccoon remains were also found, but at low numbers (1.7%, 0.6%, 2.3% occurrence, respectively).

Vegetation was often found in collected scat; herbaceous plants were found in 39% of scats, and fruits were found in 47.1% of scats. Most of the herbaceous plants found were graminoids. Common graminoid species within Poplar Creek are smooth brome (*Bromus inermis*), reed canary grass (*Phalaris arundinacea*), and tall fescue (*Schedonorus arundinaceus*). Soybean (*Glycine max*) and corn (*Zea mavs*) seeds were also found in scats. It is believed that the soybean and corn were from the agricultural fields within the study site. Common fruits found in the sampled scats included white mulberry (*Morus alba*), Toringo crabapple (*Malus toringo*), and apple (*Malus pumila*). The seeds of American linden (*Tilia americana*) were also included in the fruit category. Fruits were found more frequently in scats during summer (87.1% in 2017; 51.6% in 2018) and autumn (63.4%).

Avian, invertebrate, and human-associated items were found irregularly and in 4.7%, 9.3%, and 4.1% of scats, respectively. Avian remains were feathers and were most commonly found in summer samples (12.9% of 2017 summer scats; 9.7% of 2018 summer scats). Invertebrate items included the remains of differential grasshoppers (*Melanoplus differentialis*), numerous beetle species (order Coleoptera), mantid oothecae (order Mantodea), and crayfish species (family Cambaridae). Human-associated items included pieces of plastic, paper, food wrappers, and string.

The frequency of occurrence per food item followed the same pattern as frequency of occurrence per scat. Small mammal items were most common, with 24.0% of all items. White-tailed deer remains were the second most common item (22.3%), followed by fruit items (19.6%), herbaceous plant items (16.2%), and rabbit remains (7.3%). All other diet items individually represented less than 5.0% of total observed food items.

Certain food item presence was unevenly distributed across the study site. Muskrat and beaver were only found in scats collected from study block 1. In addition, raccoon remains were most commonly found in the scats of block 1. This is potentially explained by the presence of a carcass pit put in place by the Forest Preserve District in block 1. Carcasses of roadkill and nuisance removal animals are placed in the pit throughout the year. Human-associated items were also most prevalent in scats collected from block 3. Block 3 is believed to experience the greatest human activity of all the study blocks and, therefore, gives greater access to anthropogenic food sources. White-tailed deer fawn remains were found most frequently in scats collected in block 1. Five of the 8 confirmed fawn-containing scats were sampled from block 1.

DISCUSSION

The analysis of 172 coyote scats indicated that small mammals, white-tailed deer, fruit, and herbaceous plants are important food sources for coyotes in Poplar Creek Forest Preserve. Our findings that coyote diets largely consist small mammals is corroborated by numerous other urban coyote diet analyses (e.g. Quinn 1997, Fedriani et al. 2001, Randa et al. 2009, Larson et al. 2015, Murray et al. 2015, Poessel et al. 2017). As predicted, white-tailed deer were also frequently found in the scats of our study, which mirrors the results of other Chicago coyote diet analyses (Morey et al. 2007). These two categories experienced a shift in frequency of occurrence with changing seasons. During seasons when white-tailed deer remains were found in scats at a lower frequency, small mammal remains are found at a higher frequency (Figure 3.1). When white-tailed deer remains were found more frequently, however, small mammal remains were found at lower numbers. As expected, white-tailed deer remains were found most frequently when fawns are youngest and the most susceptible to predation (summer) and least frequently when fawns are older and can flee from predators (winter and spring). Although only 8 of the 45 summer scats containing white-tailed deer remains could be confirmed as fawn, we believe that the majority of these remains were from fawns because of the increase in both fawn presence on the landscape and the increase in white-tailed deer remains in scat during the summer season. The seasonality of deer remains in scat reinforces the hypothesis that coyotes frequently consume white-tailed deer fawns, since fawns are more susceptible to coyote predation during their first two months of life. These results also support the idea that coyotes shift their prey selection to a larger food source when it is easily attainable.

While the results suggest that white-tailed deer fawns are an important food source during the summer months, white-tailed deer remains were found in scat throughout the year. We believe that the remains found during autumn, winter, and spring are most likely from scavenged carcasses. The highest frequency of occurrence for white-tailed deer remains in our scat samples outside of the summer months was in the autumn (61.0%). These results can be explained by the high number of deer-vehicle collisions that occur during the rutting season (fall and early winter) for numerous cervid species (Steiner et al. 2014, McCance et al. 2015) which yield a high number of roadkill deer available for coyotes to scavenge. As mentioned earlier, block 1 contains an open carcass pit managed by the Forest Preserve District. This is believed to provide a yearround supply of white-tailed deer carcasses for coyotes. This is supported by the scats from block 1 having a higher occurrence of white-tailed deer remains in the winter than scats from other sites. Morey et al. (2007), who also used the site we termed block 1, also came to the conclusion that the open carcass pit may explain the high incidence of white-tailed deer remains in scats.

The variations in diet content between the study blocks exemplify the opportunistic feeding strategy of coyotes. This variation in content, in addition to the seasonal diet shift, demonstrates how coyotes adjust quickly to changes in the surrounding environment and available resources. Like other generalist species, coyotes make adjustments to their diet to minimize energy output and maximize energy input. Our results show that coyotes within our study site have a variety of food sources from which to choose, and, therefore, consume items that are amply available during different seasons. This information supports our belief that coyotes in Poplar Creek rarely hunt adult white-tailed deer. The abundance of easily acquirable food items allows coyotes to choose prey with less energy output.

MANAGEMENT IMPLICATIONS

Our results provide evidence of substantial coyote consumption of white-tailed deer and numerous small mammal species. There is potential for coyote predation to be a controlling factor on prey populations. The influence of coyotes on prey populations is likely of interest to wildlife managers as coyotes may play a role in population control strategies. Conducting coyote diet analysis in areas in which management is needed can assist in the understanding of how this predator influences a specific landscape.

White-tailed deer are known to be an important food source for coyotes in some urban areas, but this consumption varies across this species' range. White-tailed deer consumption is more prevalent during the fawn-rearing season in some urban areas, whereas it can be observed frequently throughout the year in other urban areas (Santana and Armstrong 2017). Understanding the pattern in which coyotes consume white-tailed deer within a specific area is beneficial to managers working with these species or with elements influenced by these species.

FIGURES AND TABLES

Table 3.1: Frequency of occurrence (%) of food items found in coyote scats of Poplar Creek Forest Preserve in Hoffman Estates, Illinois divided by season during which scats were collected Summer 2017–Summer 2018).

Diet Item	Summer 2017	Autumn 2017	Winter 2018	Spring 2018	Summer 2018
White-tailed deer	83.9	61.0	21.1	45.2	61.3
Small Mammals	35.5	63.4	63.2	80.6	41.9
Rabbit	6.5	9.8	42.1	16.1	9.7
Muskrat	0	0	2.6	6.5	0
Beaver	0	2.4	0	0	0
Raccoon	3.2	0	5.3	3.2	0
Bird	12.9	0	0	3.2	9.7
Invertebrates	16.1	4.9	2.6	3.2	22.6
Herbaceous Plants	25.8	43.9	39.5	45.2	38.7
Fruit	87.1	63.4	18.4	16.1	51.6
Human Associated	6.5	2.4	5.3	3.2	3.2
Other	0	4.9	2.6	3.2	3.2

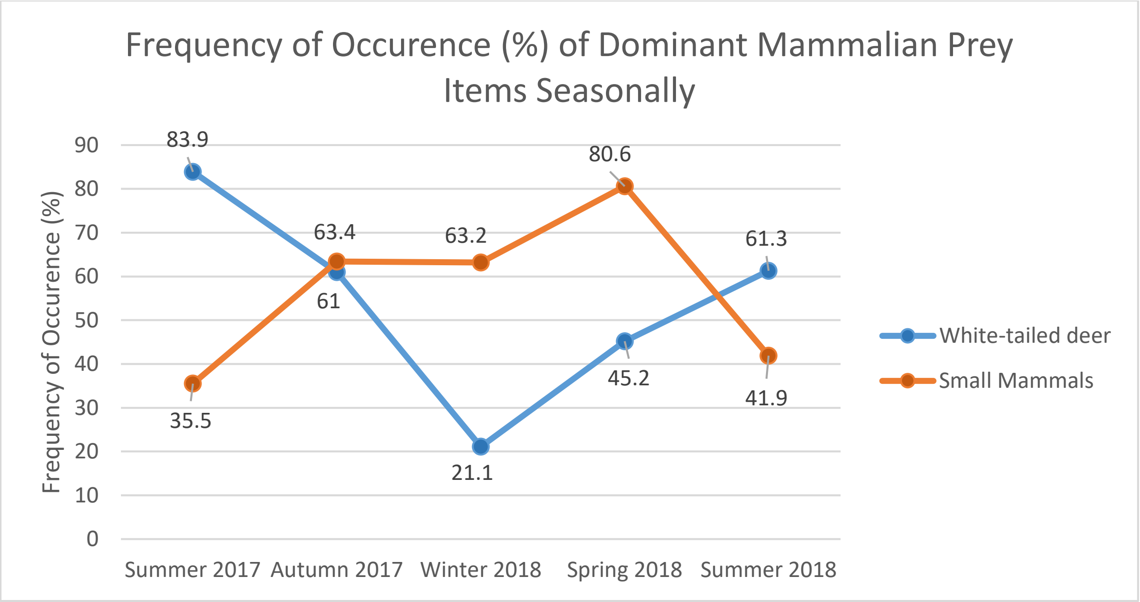

Figure 3.1: Frequency of occurrence (%) of items in coyote scats (n = 172) from Poplar Creek Forest Preserve in Hoffman Estates, Illinois that were categorized as white-tailed deer and small mammals. Frequency of occurrence was calculated for each collection season of this study (summer 2017–summer 2018).

LITERATURE CITED

Barrette, C., and F. Messier. 1980. Scent-marking in free-ranging coyotes, *Canis latrans*. Animal Behavior 28:814–819.

Brown, J. S., J. W. Laundré, and M. Gurung. 1999. The Ecology of Fear: Optimal Foraging, Game Theory, and Trophic Interactions. Journal of Mammalogy 80:385–399.

Cepek, J. D. 2004. Diet composition of coyotes in the Cuyahoga Valley National Park, Ohio. Ohio Journal of Science 104:60-64.

Crimmins, S. M., J. W. Edwards, and J. M. Houben. 2012. *Canis latrans* (coyote) habitat use and feeding habits in central West Virginia. Northeastern Naturalist 19:411-420.

Debelica A., and M. L. Thies. 2009. Atlas and key to the hair of terrestrial Texas mammals. Special Publications of the Museum of Texas Tech University, Number 55.

Fedriani, J. M., T. K. Fuller, and R. M. Sauvajot. 2001. Does availability of anthropogenic food enhance densities of omnivorous mammals? An example with coyotes in southern California. Ecography 24:325-331.

Grovenburg, T. W., C. C. Swanson, C. N. Jacques, R. W. Klaver, T. J. Brinkman, B. M. Burris, C. S. Deperno, and J. A. Jenks. 2011. Survival of white-tailed deer neonates in Minnesota and South Dakota. Journal of Wildlife Management 75:213-220.

Hildreth, M. B., D. S. Blunt, and J. A. Oaks. 2004. Lethal effects of freezing *Echinococcus multilocularis* eggs at ultralow temperatures. Journal of Parasitology 90:841-844.

Kilgo, J. C., H. S. Ray, M. Vukovich, M. J. Goode, and C. Ruth. 2012. Predation by coyotes on white-tailed deer neonates in South Carolina. Journal of Wildlife Management 76:1420–1430.

Klare, U., J. F. Kamler, and D. W. Macdonald. 2011. A comparison and critique of different scat-analysis methods for determining carnivore diet. Mammal Review 41:294-312.

Larson, R. N., D. J. Morin, I. A. Wierzbowska, and K. R. Crooks. 2015. Food habits of coyotes, gray foxes, and bobcats in a coastal southern California urban landscape. Western Northern American Naturalist 75:339-347.

Lukasik, V. M., and S. M. Alexander. 2012. Spatial and temporal variation of coyote (*Canis latrans*) diet in Calgary, Alberta. Cities and the Environment 4: Article 8.

McCance, E. C., R. K. Baydeck, D. J. Walker, and D. N. Leask. 2015. Spatial and temporal analysis of factors associated with urban deer-vehicle collisions. Human-Wildlife Interactions 9:119-131.

Morey, P.S., E.M., Gese, and S.D., Gehrt. 2007. Spatial and Temporal Variation in the Diet of Coyotes in the Chicago Metropolitan Area. The American Midland Naturalist 158:147–161.

Mumma, M. A., J. R. Adams, C. Zieminski, T. K. Fuller, S. P. Mahoney, and L. P. Waits. 2016. A comparison of morphological and molecular diet analyses of predator scats. Journal of Mammalogy 97:112-120.

Murray, M. H., A. Cembrowski, A. D. M. Latham, V. M. Lukasik, S. Pruss, and C. C. St. Clair. 2015. Greater consumption of protein-poor anthropogenic food by urban relative to rural coyotes increases diet breadth and potential for human-wildlife conflict. Ecography 38:1235-1242.

Newsome, S. D., H. M. Garbe, E. C. Wilson, and S. D. Gehrt. 2015. Individual variation in anthropogenic resource use in an urban carnivore. Oecologia 178:115-128.

Piccolo, B. P., T. R. Van Deelen, K. Hollis-Etter, D. R. Etter, R. E. Warner, and C. Anchor. 2010. Behavior and survival of white-tailed deer neonates in two suburban forest preserves. Canadian Journal of Zoology 88:487–495.

Poessel, S. A., E. C. Mock, and S. W. Breck. 2017. Coyote (*Canis latrans*) diet in an urban environment: variation relative to pet conflicts, housing density, and season. Canadian Journal of Zoology 95:287-297.

Quinn, T. 1997. Coyote (Canis latrans) food habits in three urban habitat types of western Washington. Northwest Science 71:1-5.

R Development Core Team. 2018. R: a language and environment for statistical computing. Vienna (Austria): R Foundation for Statistical Computing [cited 2018 October 19].

Randa, L. A., D. M. Cooper, P. L. Meserve, and J. A. Yunger. 2009. Prey switching of sympatric canids in response to variable prey abundance. Journal of Mammalogy 90:594-603.

Saalfeld S. T. and S. S. Ditchkoff. 2007. Survival of neonatal white-tailed deer in an exurban population. The Journal of Wildlife Management 71:940-944.

Santana, E. and J. Armstrong. 2017. Food habits and anthropogenic supplementation in coyote (Canis latrans) diets along an urban-rural gradient. Human-Wildlife Interactions 11:156-166.

Schrecengost, J. D., J. C. Kilgo, D. Mallard, S. Ray, and K. V. Miller. 2008. Seasonal food habits of the coyote in the South Carolina coastal plain. Southeastern Naturalist 7:135-144.

Shuman, R. M, M. J. Cherry, T. N. Simoneaux, E. A. Dutoit, J. C. Kilgo, M. J. Chamberlain, and K.V. Miller. 2017. Survival of white-tailed deer neonates in Louisiana. Journal of Wildlife Management 81:834-845.

Steiner, W., F. Leisch, and K. Hackländer. 2014. A review on the temporal pattern of deer-vehicle accidents: Impacts of seasonal, diurnal and lunar effects in cervids. Accident Analysis and Prevention 66:168-181.

Swingen, M. B., C. S. DePerno, and C. E. Moorman. 2015. Seasonal coyote diet composition at a low-productivity site. Southeastern Naturalist 14:397-404.

Chapter 4: Vigilant and Approach Behavior of White-tailed Deer while Foraging with and without an Indicator of Coyote Presence in a Suburban Forest Preserve of Chicago

INTRODUCTION

Investigating how a prey species responds to predator presence is important for understanding how these species utilize an area in which they coexist. If a species is fearful of another, it can be expected that the former would avoid interaction with the latter based on the "ecology of fear" framework (Brown et al. 1999). Depending on how strongly that animal is fearful of an interaction, that animal may alter their behavior to limit those interactions.

One way that prey species are known to avoid interaction with higher trophic species (i.e. predation) is through vigilance during foraging. Observed in many prey species, vigilance during foraging increases observation of the surrounding area for potential threats. While foraging, there is a tradeoff between spending time consuming resources and being vigilant (Brown 1999). Previous studies have used this tradeoff to analyze antipredator behavior of numerous cervid species, including white-tailed deer (*Odocoileus virginianus*) (Lashley et al. 2014, Waser et al. 2014, Cherry et al. 2015, Schuttler et al. 2015, Gulsby et al. 2018). Greater time allocated towards vigilance is also associated with species experiencing higher risks of predation (Périquet et al. 2012). Therefore it is expected that prey species would allocate more time to vigilance while foraging if they perceive a greater chance of predation.

In the Chicago region, white-tailed deer fawns are known to be prey of coyotes (*Canis latrans*) while adults are rarely predated upon (Etter et al. 2002, Morey et al. 2007, Piccolo et al. 2010). This variance in predation threat has potential to elicit different foraging responses between age classes and sexes of deer. Presumably, white-tailed deer individuals who are at greater risk to be affected by coyotes would demonstrate stronger behavioral responses than those who are not. We predicted that if white-tailed deer were to respond differently between age classes and sexes to the presence of coyotes, fawns and their mothers would be more likely to show antipredator behavior than bucks and does without fawns.

Following the "ecology of fear" theory, we predicted that deer perceiving a higher risk of predation would allocate more time to vigilance than deer who perceive little predation risk. In addition, when taking the predation risk allocation hypothesis (Lima and Bednekoff 1999) into account, we believe that deer who are exposed to a temporally limited high-risk environment would increase vigilance during that time. Therefore, we predicted that white-tailed deer fawns and does with young fawns would show greater levels of vigilance than adult males during the summer but similar levels during other times of the year.

METHODS

To test our hypothesis, we observed vigilance, as well as approach behavior, of white-tailed deer while foraging with and without an indicator of coyote presence using bait stations and camera traps. This also gave us the opportunity to introduce coyote urine, an indicator of coyote presence, to the sites. Predator urine has been used in previous studies investigating white-tailed deer behavior, because it is a substance regularly encountered in the natural environment (Swihart et al. 1991, Waser et al. 2014, Champagne et al. 2017).

Study Area

Observation sites were set in a forest preserve located in a suburb of Chicago. This preserve has been used for white-tailed deer and coyote research since the 1990s by the Forest Preserves of Cook County and Max McGraw Wildlife Foundation. Due to the extensive amount of research conducted on this site, information on the populations of both white-tailed deer and coyotes is abundant and readily available. The Poplar Creek Forest Preserve was specifically located in Hoffman Estates, Illinois, a northwest suburb of Chicago. White-tailed deer and coyotes occurred at this site in high densities (>23 deer/km^2 (Piccolo et al. 2010); 5–10 coyotes/km^2 (Gehrt et al. 2011)). Poplar Creek was comprised of a variety of habitat types including woodland, prairie, and wetland. This area also contained agricultural fields. Recreational areas were also found throughout the preserve, including picnic groves, trails, and a model airplane field. Although trails were abundant throughout our study sites, off-trail usage by the public was common. We acknowledge that this off-trail usage could potentially influence our behavior studies. Off-trail use can impact foraging vigilance at the study sites throughout the year and can potentially lead to higher incidents of vigilance. Along the borders of the preserve were residential areas, railroad, and an 8-lane highway. Roadways ran through Poplar Creek, breaking the area up into blocks. For our study, we used three of these blocks to establish forging study sites (block 1, block 2, and block 3). Other parts of the overall white-tailed deer and coyote relationship study were also conducted in these three study blocks. Chapter 2 goes into further detail of the characteristics of each study block, the Poplar Creek Forest Preserve, and the Chicago metropolitan area.

Site Establishment

Observation sites were established in each of the study blocks in the Poplar Creek Forest Preserve (Figure 4.1). Two sites (one control and one test) were developed in each of the 3 blocks providing a total of 6 observation sites. Each site was placed along the edge of a wooded area adjacent to either a grassland or agricultural field. Sites were also developed on or near deer trails to ensure that the site would be found quickly after bait deployment. Specific locations were chosen based on habitat requirements and being located far enough away from trails and parking lots to reduce the potential of human influence. We also placed sites a minimum of 50 m apart to avoid the potential effects of experimentally-placed predator odor used within our test sites on our control sites.

Behavior Survey

Behavioral surveys occurred once approximately every three months starting in July of 2017 and ending in July of 2018. Surveys began with the placement of a feed block at each of the observation sites. Feed blocks were placed out in the open so that they could be readily found by deer and observed by researchers. Trail cameras were placed at the sites facing the feed blocks. Each site received two cameras: a still image camera and a video camera. The two cameras at each site ensured that most visitations were captured and that all deer behaviors were recorded. Cameras were set approximately 3–4 m from the feed block and were motion triggered. Still image cameras were set to take 3 images per trigger with no delay between triggers. Video cameras were set to record for 1 minute with no delay between triggers. We used cameras with infrared ability so that we could capture behavior at all hours of the day.

Behavioral surveys took place for 7 days and 6 nights. After 3 nights of having deployed the camera, experimental sites were sprayed with coyote urine directly next to the feed block and control sites were treated with distilled water. Three days after the sites were treated, cameras were taken down and images and videos were downloaded for analysis.

Still Image and Video Analysis

Collected camera data was analyzed to document individual and group characteristics and foraging behavior of the white-tailed deer. The characteristics recorded were sex, age class, and group size of the deer in the photos and videos. Videos captured within a 5-minute interval were considered the same individual if the deer was not identifiable by external characteristics (e.g. scars, unique antler characteristics). Videos captured outside of a 5-minute interval were recorded as separate individuals. Age of observed deer were labeled as adult or juvenile based on pelage and morphological characteristics. Sex was identified by the presence or absence of antlers or pedicles. Group sizes were recorded based on the number of white-tailed deer in the frame. Definitive group sizes cannot be measured using this survey technique, but our method produced an estimate to the number of individuals visiting the bait. Group composition was also recorded to determine the proportion of males, females, and juveniles of each group. Time data and the application of coyote urine was also documented for each image.

Foraging behavior was categorized as “vigilant foraging behavior” or “non-vigilant foraging behavior” for both photos and videos using the behavior classification system used by Lashley et al. (2014). “Non-vigilant foraging behavior” was characterized by the head of a deer positioned toward the ground, below stomach line, and actively foraging. Deer with the head positioned up and above the stomach line of the body were classified as exhibiting “vigilant foraging behavior”.

In addition to vigilance, approach behavior was analyzed using videos. We used this data as a way to investigate how cautious a deer was when approaching the bait. For this analysis, posture and movement were used to classify behavior from the time when the deer entered the frame to when it reached the block. Approach behavior was classified as one of three categories: “not hesitant”, “hesitant”, and “does not approach”. Behavior was categorized as “not hesitant” when the deer immediately walked up to the bait block, did not scan the area, and showed no signs of caution (e.g. leaning back, sniffing the air around the block, taking steps back, head bobbing, circling). “Hesitant” was used to describe a deer that exhibited signs of caution, scanned the surrounding area, and did not approach the bait block immediately. Behavior was listed as “does not approach” if the deer came into the frame, looked at the bait at least once, showed signs of caution, and never reached the bait block. Variances in behavior between sexes, age classes, and group sizes, as well as how those behaviors change seasonally within each category in response to coyote urine, was analyzed to look for significant changes in vigilance.

Proportion of time spent vigilant was evaluated through analysis of variance (ANOVA) and generalized linear mixed models (GLMMs). For the GLMM analysis, head position was the dependent variable; sex, age class, group size, time of day (day or night), and fawn presence were independent variables. We used season as our random variable. For analyzing approach behavior, chi-squared tests of independence were used to determine if these behaviors were independent or dependent on the presence of coyote urine, sex, age class, and group size. All analyses used program R (R Development Team 2018). R package lme4 was used for GLMM analysis (Bates et al. 2018).

RESULTS

Vigilant Behavior Results

We collected a total of 11,135 still images of white-tailed deer with 14,406 detections of individual white-tailed deer, from 295 visits to our study sites. Visits were defined as a collection of images of the same individual or group, detected within five minutes of each other. There were 5,104 detections of adult females, 6,341 detections of adult males, and 1,582 detections of juvenile white-tailed deer. The detections of white-tailed deer where sex or head position could not be determined (n=1,379) were not used for analysis. We did, however, include these deer in our calculations of group size.

Average proportion of time spent vigilant for our test sites, before the administration of coyote urine, was 0.51 and after the administration of coyote urine was 0.42 (Table 4.1). Control sites had an average proportion of time spent vigilant of 0.38 before water administration and 0.49 after treatment. Results of GLMM indicated that there were no differences in time spent vigilant between treatments, as well as between all other factors examined in our study (Pr(>z) > 0.05). Results of the one-way ANOVA tests did not find variation in treatment (F value = 0.828, Pr(>F) = 0.48). The interaction between season and treatment was found to be significant after a two-way ANOVA test (F value = 2.208, Pr(>F) = 0.028).

As expected, adult females spent a greater proportion of time vigilant than both adult males and juveniles. The proportion of time spent vigilant by adult females was 39.6% greater than adult males and 26.3% greater than juveniles. Sex and age class, however, were not found to be significant after one-way ANOVA analysis. For adult males and females, vigilance was greatest in the summer surveys and in the autumn. Juveniles showed greater vigilance in the summer and spring surveys. None of the sex and age classes showed increased vigilance with the presence of coyote urine.

Season was the only informative parameter of vigilant behavior (F value = 2.471, Pr(>F) = 0.046). The proportion of time spent vigilant was highest during the summer and autumn and lowest in the winter and the spring. The first summer survey had the highest vigilance (0.61) and spring had the lowest (0.33). There was, however, a difference in vigilance between the two summer surveys (0.61 and 0.42, respectively). All other factors (time of day, fawn presence, and group size) were not found to influence vigilant behavior.

Approach Behavior Results

A total of 148 videos was used in the analysis of approach behavior. These videos captured the behavior of deer when they first were observed on camera. Although many of the videos captured during our study captured groups of deer, we only included in our analysis the individuals that looked at the feed block at least once in this analysis. This eliminates any deer that were not have captured noticing the feed block. We also excluded any video that was the first of a recorded visit, but did not show how that deer approached the bait. Sixty of the videos used in this analysis were of does, 64 were of bucks, and 24 were of juveniles.

The application of coyote urine resulted in little change of approach behavior when compared to the behavior at those same sites before urine application, as well as at control sites.

“Not hesitant” was the most commonly listed behavior for each treatment classification (control sites pre-water application = 72.0%, control sites post-water application = 71.9%, treatment sites pre-urine application = 62.1%, and treatment sites post-urine application = 70.3%). The proportion of approach videos that showed “hesitant” behavior decreased after the application of coyote urine (pre-coyote urine = 17.2%, post-coyote urine = 16.2%) (Table 4.2). The proportion of videos that showed deer that never reached the bait block also decreased after the application of coyote urine (pre-coyote urine = 20.7%, post-coyote urine = 13.5%). The chi-squared test implied that approach behavior was independent of the treatment at the site (chi-squared = 2.73, P = 0.84).

The approach behavior of bucks, does, and fawns showed some variation. Behavior categorized as “not hesitant’ was the most common for all three sex/age classes (71.9% of videos of bucks, 75.0% of videos of does, and 50.0% of videos of fawns). The behavior of fawns varied the most from the other classes with the largest proportion of videos where the deer never approached the bait block (33.3%). When using a combined category for sex and age class (bucks, does, and fawns), the results of the chi-squared test suggest independence between sex/age class and approach behavior (chi-squared = 6.11, P = 0.19). The results of this test when using strictly age classes (adult, juvenile) imply dependence between age class and approach behavior (chi-squared = 5.96, P = 0.05). When using only sex as a variable (Male and Female only; Juveniles were removed from the analysis), the chi-squared test suggest independence of sex and approach behavior (chi-squared = 0.17, P = 0.92).

The season in which a video was collected, as well as the group size of the deer recorded, were shown to potentially have influence over approach behavior. The number of approach videos collected each season showed a high degree of variation (Summer 2017 = 5, Autumn 2017 = 49, Winter 2018 = 53, Spring = 9, Summer 2018 = 32), leading to the use of proportions to analyze this data. Most approaches were classified as “not hesitant” in all seasons with the exception of Spring, which had equal representation of all 3 behavior classifications (Summer 2017 = 60.0%, Autumn 2017 = 56.2%, Winter 2018 = 69.8%, Spring = 33.3%, Summer 2018 = 96.9%). Using the chi-squared test for analysis, seasons were shown to have some influence on the approach behavior of the deer in Poplar Creek (chi-squared = 23.78, P = 0.002). Approach behavior was also suggested to be dependent on group size (chi-squared = 20.07, P = 0.01). Group sizes ranged from 1 to 7 individuals. A group size of one was most frequently recorded and seven was the least frequent (N = 108 and N = 1, respectively). “Not hesitant’ was the most common behavior for the smaller group sizes (1–3) and “does not approach” was the most common behavior for larger group sizes (4–7).

DISCUSSION

The presence of coyote urine at the baited sites did not increase vigilant behavior when foraging or cautious behavior when approaching a food source. We predicted if deer were fearful of coyotes, we would see increased vigilance and cautious behavior when an indicator of coyote was present at a foraging site. Due to high coyote densities in Poplar Creek, deer may encounter coyote urine regularly and have become habituated to the presence of coyote urine. Further research is needed to determine what type of indication of coyote presence is needed for deer to respond with increased antipredator behavior.

Season was the greatest predictor of vigilant behavior and age class, season, and group size had the most influence over approach behavior. It is important to note, however, that the sample sizes for each season varied with a low number of photos captured in the first summer and spring and a low number of videos captured in the spring compared to other seasons. Low sample numbers can potentially skew our results. We expected age class and group size to show some influence over foraging behaviors because of what is known of the conspecific interactions of deer. Older and larger deer will often push younger and smaller deer away from foraging areas (Townsend and Bailey 1981, Donohue et al. 2013, Stone et al. 2017). It can be expected some deer will alter their behavior when around other individuals. This can also explain the greater level of caution exhibited by juveniles when approaching the bait sites.

The results of previous studies on foraging behavior of white-tailed deer vary. Our results on the effects of coyote urine on deer foraging behavior differed from the results of Cherry et al. (2015), where males showed an increase of vigilant behavior with greater coyote presence. Our results on vigilance complement those found by Schuttler et al. (2015), who found that vigilance did not increase with greater coyote activity. Similar to the results of Cherry et al. (2015), we found a negative behavioral response (increase in “does not approach” behavior) to greater group sizes on foraging behavior. Lashley et al. (2014), however, found that greater group sizes had a positive effect on the foraging time of white-tailed deer. Each of these studies were conducted in different regions and differed in habitat structure, suggesting that deer behavioral responses may be influenced by the surrounding environment.

MANAGEMENT IMPLICATIONS

Coyote presence is a concern for many managers of deer. In addition to understanding the effect of coyotes on deer via predation, understanding how deer respond behaviorally to this predator is pertinent to managing these two species. Our study provides evidence that white-tailed deer in high coyote density areas do not alter their foraging behavior when an indicator of coyote is present. This provides evidence that at the landscape level, coyotes may have little impact on deer behavior in this high density areas. Our results are likely of greatest interest to managers in areas of high deer and coyote densities where understanding deer behavior and movement is needed to develop effective management decisions. These results are also likely of interest to managers of areas of recent coyote colonization because these results provide insight on how deer might respond to coyotes if the coyote population continues to grow in those areas.

In addition, as a nuisance animal in some areas, understanding how deer respond to predator urine in an area where they frequently come into contact with that predator may provide insight on what methods should and should not be used to deter deer foraging. The results of our study, as well as other studies, indicate that coyote urine may not be an effective deterrent in these high coyote density areas. We believe that the habituation to coyote presence in these areas is the result of the low predation risk on adult deer. The results of our study may be observed in other areas of high coyote density and low predation risk. Future research on the behavioral responses of deer and whether it reflects the predation risk across this species range would be beneficial to managers in predicting and understanding deer behavior and deciding what management actions are best suited for their area.

FIGURES AND TABLES

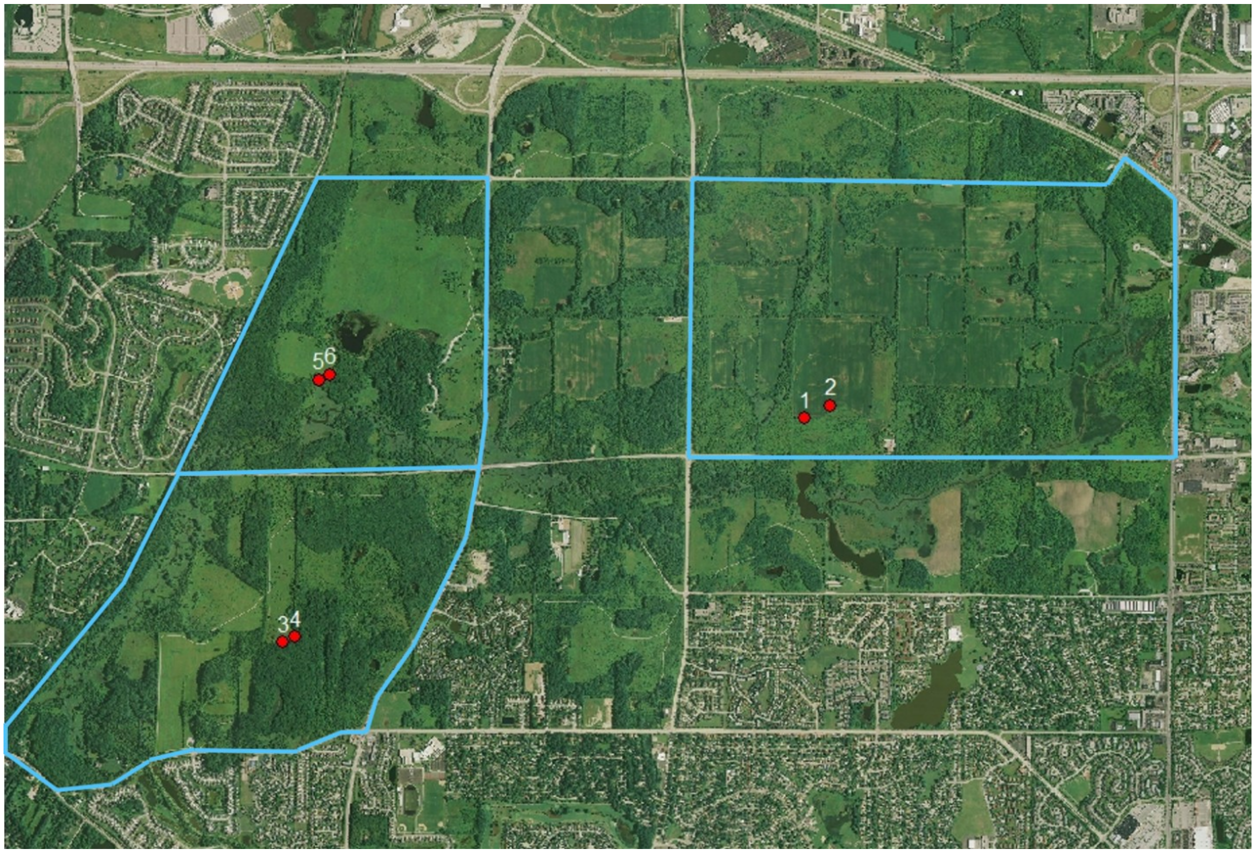

Figure 4.1: Locations of the foraging behavior test sites in Poplar Creek Forest Preserve in Hoffman Estates, Illinois (2017–2018). Sites 1 and 2 are within study block 1, sites 3 and 4 are in study block 2, and sites 5 and 6 are in study block 3.

Table 4.1: Proportion (P) of photos (n = 11,135) of deer showing "vigilant foraging behavior" at each treatment site for each sex/age class at Poplar Creek Forest Preserve, Hoffman Estates, Illinois (2017–2018).

	Sex/Age Class							
	Female		Male		Juvenile		All Deer	
Test Treatment	n	P	n	P	n	P	n	P
Control Pre	1,950	0.48	2,226	0.27	385	0.40	4,558	0.38
Control Post	776	0.57	495	0.36	55	0.51	1,326	0.49
Test Pre	1,445	0.55	382	0.55	730	0.42	2,557	0.51
Test Post	886	0.51	3,245	0.41	691	0.36	4,822	0.42

Table 4.2: Proportion (P) of videos (n = 148) showing each approach behavior by deer at the different treatment sites in Poplar Creek Forest Preserve, Hoffman Estates, Illinois (2017–2018).

	Approach Behavior					
	Not Hesitant		Hesitant		Does Not Approach	
Test Treatment	n	P	n	P	n	P
Control Pre	36	0.72	4	0.08	10	0.20
Control Post	23	0.72	4	0.13	5	0.16
Test Pre	18	0.62	5	0.17	6	0.21
Test Post	26	0.70	6	0.16	5	0.14

LITERATURE CITED

Bates D., M. Maechler, B. Bolker, and S. Walker. 2018. Lme4: Linear mixed-effects models using Eigan and S4. R package version 1.1-18-1 [cited 2018 October 19].

Brown, J. S. 1999. Vigilance, patch use and habitat selection: foraging under predation risk. Evolutionary Ecology Research 1:49-71.

Brown, J. S., J. W. Laundré, and M. Gurung. 1999. The ecology of fear: optimal foraging, game theory, and trophic interactions. Journal of Mammalogy 80:385–399.

Champagne, E., L. Perroud, A. Dumont, J. –P. Tremblay, and S. D. Côté. 2017. Neighboring plants and perception of predation risk modulate winter browsing by white-tailed deer (*Odocoileus virginianus*). Canadian Journal of Zoology 96:117-125.

Cherry, M. J., L. M. Conner, and R. J. Warren. 2015. Effects of predation risk and group dynamics on white-tailed deer foraging behavior in a longleaf pine savanna. Behavioral Ecology 26:1091-1099.

Donohue, R. N., D. G. Hewitt, T. E. Fulbright, C. A. Deyoung, A. R. Litt, and D. A. Draeger. 2013. Aggressive behavior of white-tailed deer at concentrated food sites as affected by population density. Journal of Wildlife Management 77:1401-1408.

Etter, D., K. Hollis, T. Van Deelen, D. Ludwig, J. Chelsvig, C. Anchor, and R. Warner. 2002. Survival and movements of white-tailed deer in suburban Chicago, Illinois. Journal of Wildlife Management 66:500-510.

Gehrt, S. D., J. L. Brown, and C. Anchor. 2011. Is the urban coyote a misanthropic synanthrope? The case from Chicago. Cities and the Environment 4:Article 3.

Gulsby W. D., M. J. Cherry, J. T. Johnson, L. M. Connor, and K. V. Miller. 2018. Behavioral response of white-tailed deer to coyote predation risk. Ecosphere 9:e02141.

Lashley, M .A., M. C. Chitwood, M. T. Biggerstaff, D. L. Morina, C. E. Moorman, and C. S. DePerno. 2014. White-tailed deer vigilance: the influence of social and environmental factors. PLoS ONE 9:e90652.

Lima, S. L., and P. A. Bednekoff. 1999. Temporal variation in danger drives antipredator behavior: the predation risk allocation hypothesis. The American Naturalist 153:649-659.

Morey, P. S., E. M. Gese, and S. D. Gehrt. 2007. Spatial and temporal variation in the diet of coyotes in the Chicago Metropolitan Area. The American Midland Naturalist 158:147–161.

Périquet S., L. Todd-Jones, M. Valeix, B. Stapelkamp, N. Elliot, M. Wijers, O. Pays, D. Fortin, H. Madzikanda, H. Fritz, D. W. Macdonald, and A. J. Loveridge. 2012. Influence of immediate predation risk by lions on the vigilance of prey of different body size. Behavioral Ecology 23:970-976.

Piccolo, B. P., T. R. Van Deelen, K. Hollis-Etter, D. R. Etter, R. E. Warner, and C. Anchor. 2010. Behavior and survival of white-tailed deer neonates in two suburban forest preserves. Canadian Journal of Zoology 88:487–495.

R Development Core Team. 2018. R: a language and environment for statistical computing. Vienna (Austria): R Foundation for Statistical Computing [cited 2018 October 19].

Schuttler S. G., A. W. Parsons, T. D. Forrester, M. C. Baker, W. J. McShea, R. Costello, and R. Kays. 2016. Deer on the lookout: how hunting, hiking and coyotes affect white-tailed deer vigilance. Journal of Zoology 301:320-327.

Stone, D. B., M. J. Cherry, J. A. Martin, B. S. Cohen, and K. V. Miller. 2017. Breeding chronology and social interactions affect ungulate foraging behavior at a concentrated food source. PLoS ONE 12:e0178477.

Swihart, R. K., J. J. Pignatello, and M. J. I. Mattina. 1991. Aversive responses of white-tailed deer, *Odocoileus virginianus*, to predator urines. Journal of Chemical Ecology 17:767–777.

Townsend, T. W. and E. D. Bailey. 1981. Effects of age, sex and weight on social rank in penned white-tailed deer. American Midland Naturalist 106:92-101.

Waser, N. M., M. V. Price, D. T. Blumstein, S. Reneé Arózqueta, B. D. Castro Escobar, R. Pickens, and A. Pistoia. 2014. Coyotes, deer, and wildflowers: diverse evidence points to a trophic cascade. Naturwissenschaften 101:427–436.

Chapter 5: Static and Dynamic Interaction of White-tailed Deer and Coyotes in a Suburban Forest Preserve of Chicago

INTRODUCTION

As a predator species, coyotes have the ability to influence the prey species in the areas in which they co-inhabit. This influence has potential to reach outside of the act of predation. Where predator-prey relationships exist, prey species respond to threats through antipredator behavior (Brown et al, 1999). Two forms of antipredator behavior are vigilance (investigated in chapter 4) and avoidance. Avoidance can be exhibited both temporally and spatially. Temporal avoidance allows the joint use of a space but at differing times, whereas spatial avoidance allows simultaneous activity but in differing spaces.

Research on the avoidance of coyotes (*Canis latrans*) by white-tailed deer (*Odocoileus virginianus*) is extremely limited. Most avoidance studies focus on using scat, tracks, signs of herbivory, and cameras to determine whether deer utilize areas lacking high coyote densities greater than areas that do (Magle et al. 2014, Waser et al. 2014, Pierce et al. 2015, Jones et al. 2016). Another avoidance study investigated the avoidance of areas with high coyote and other predator densities by does with fawns (Duquette et al. 2014). Each of these studies used different methods of measuring avoidance (e.g. presence/absence, shifting of foraging areas etc.), making result comparison difficult. The results of these studies varied in terms of whether the authors determined avoidance was present or not, suggesting that the avoidance of coyotes by white-tailed deer is not homogenous across populations and that this behavior is potentially dependent on multiple factors.

As a prey species, white-tailed deer are expected to respond to coyote presence. The specific predator-prey relationship of the coyote and deer populations in the Chicago region, however, has potential to yield a unique response from deer in this system. The coyotes in this area are believed to primarily hunt and consume deer fawns rather than adult deer (Etter et al. 2002, Morey et al. 2007, Piccolo et al. 2010). The difference in predation between age classes suggests that the behavior of deer may differ between age classes and reproductive seasons. The primary objective of our study was to determine if deer at our study site avoid coyotes through the investigation of static and dynamic interactions. Static interactions are generally determined through the examination of joint-space use whereas dynamic interactions are determined through the investigation of how the movements of two individuals are associated (Macdonald et al. 1980). One of the ways dynamic interaction analysis is used is to investigate attraction and avoidance behavior between individual animals (Doncaster 1990, Long et al. 2014). Static interaction is often used as an *a priori* indicator for dynamic interactions (Long et al. 2014). We, therefore, expected that dyads with a larger proportion of home range overlap would have greater dynamic interaction than those with smaller proportions. We also wanted to determine, if avoidance was observed, whether the antipredator behavior of avoidance differs between adult white-tailed deer and fawns. We also set out to explore differences in avoidance behavior of deer between the months when fawns are most susceptible to predation (April-August) and the months in which they are least threatened (September-March). We expected our results to present little indication of avoidance at our study site based on the high coyote densities in this area. We predicted that because deer are likely coming into contact with coyotes frequently, deer would not be able to fully avoid coyotes or they would become habituated to coyote presence. If avoidance was observed, we predicted that it would be exhibited by fawns or does with fawns because coyotes are the greatest threat to these deer than to adult bucks and does without fawns.

METHODS

We had the opportunity to investigate avoidance through the use of location data. Concurrent research occurring within our study area involved radio-tracking coyotes and deer. This allowed the utilization of these study animals to perform avoidance testing. With this ability, we were able to use location data to conduct interaction behavior analysis. To our knowledge, our study is the first to concurrently monitor deer and coyotes specifically to measure avoidance.

Study Area

Our research occurred in the Poplar Creek Forest Preserve. Poplar Creek was a 1,825 ha preserve located in the northwest suburbs of Chicago in the town of Hoffman Estates, Illinois. Poplar Creek was composed of woodlands, prairies, wetlands, agricultural fields, and recreational areas. Bordering the preserve were residential areas, businesses, railroads, and an 8-lane highway. This preserve was also intersected by roadways, creating natural ‘blocks’ of habitat. We used three of these blocks for trapping white-tailed deer and coyotes. We used the same three blocks as the other parts of the overall white-tailed deer and coyote relationship research. Chapter 2 describes these blocks, as well as Poplar Creek and the Chicago region, in greater detail. The surrounding forest preserve areas adjacent to the study blocks were similar in habitat composition of the study blocks. We utilized this area for avoidance testing because of the high white-tailed deer and coyote densities (>23 deer/km^2 (Piccolo et al. 2010); 5–10 coyotes/km^2 (Gehrt et al. 2011)) and to expand our understanding of these populations. This also provided study animals for data collection that were collared in years prior.

Deer Capture

All deer trapping and processing was conducted by the Forest Preserves of Cook County wildlife biologists in accordance with the districts deer management program. Trapping, collaring, and processing methods for white-tailed deer most closely followed those used by Etter et al. (2002). Capturing and handling procedures of deer followed the guidelines of the American Society of Mammalogists (Sikes 2016). Deer trapping occurred from November-March (2017-2018) each year of our study. Trapping took place in the morning and evening; times of day when deer were most active and when there are few visitors in the preserve. Deer were trapped using drop nets, rocket nets, and darts with chemical immobilization fired from the ground over baited sites. These sites were baited in the weeks prior to capture attempts to habituate deer to the site and equipment. Trapping technique was dependent on weather and capture site. After capture, deer were immobilized with xylazine hydrochloride and Telozol (Zoetis Services, Parsippany, NJ, USA). Immobilized deer were then fitted with a very high frequency (VHF) collar (ATS M2510B; Advanced Telemetry Systems, Inc., Isanti, MN, USA). Adult does (>1.5 yr) were also fitted with vaginal implant transmitters (VIT) (ATS M3900; Advanced Telemetry Systems, Inc., Isanti, MN, USA) to assist with locating fawns after parturition for the fawn survival section of our study (Chapter 2). Age class and sex were recorded for each deer. Age was determined by examining tooth wear and replacement. After all measurements were taken and a radio collar fitted, the effects of xylazine hydrochloride were reversed with the administration of yohimbine hydrochloride intravenously or intramuscularly (Kilgo et al. 2012). After recovering from immobilization, deer were released and monitored.

Coyote Capture

Coyote trapping, collaring, and processing followed the protocols used by Newsome et al. (2015). Capturing and handling procedures of coyotes were approved by Ohio State University's Institutional Animal Care and Use Committee (Protocol Nos. 2013A00000012) and followed the guidelines of the American Society of Mammalogists (Sikes 2016). Coyotes were trapped using padded foothold traps and cable restraints. Coyote trapping occurred throughout the year with the exception of the summer months. Trapping in the summer is not recommended due to the dangers of heat and potential trapping of coyotes with pups. For processing, coyotes were transported to a lab facility. Coyotes were immobilized using Telazol. After immobilization, coyotes were fitted with VHF collars (ATS M2220; Advanced Telemetry Systems, Inc., Isanti, MN, USA). Age class and sex were documented for each individual captured. Body measurements and ectoparasite abundance was also recorded. Blood and hair samples were collected for each individual for concurrent genetic and stress research. Coyotes were held until the effects of Telazol diminished. Fully recovered coyotes were then released at their respective capture sites.

Deer and Coyote Monitoring

Collared deer and coyotes were relocated by triangulation using a 4-element fixed Yagi antenna mounted on the roof of a vehicle. The program Locate III (Nams 2006) was used to determine animal locations through triangulation. Day locations were collected once a week on average. Night location sets were collected twice a month on average. Night location sets consisted of five relocations with an hour interval between locations. By collecting five consecutive locations in a night, the movement of an individual animal through their home range is obtained. Relocations were collected throughout the year. Doe relocations increased during the months leading up to parturition and after to assist in the fawn survival study.

Deer and Coyote Location Collection for Avoidance Analysis

Once every month from August 2017 through July 2018, deer and coyote locations were collected for avoidance analysis. The locations of deer and coyotes residing within a study block were collected as a group. In order to perform the avoidance analysis, concurrent locations for the animals within each group were needed. Due to our inability to collect all locations at the same time, we designated locations collected within 30 minutes of each other as concurrent. One concurrent day location was collected for each grouping and a single set of five consecutive concurrent night locations were collected per group. The night location sets were collected once every hour for 5 hours starting at sunset. In order to perform this collection method, two technicians in two antenna-fitted vehicles were needed to triangulate all of the deer and coyotes within the 30 minute time frame.

Analysis of Avoidance Data

For analysis, we examined the static and dynamic interaction of each deer-coyote dyad within the three study blocks. We used both static and dynamic interaction tests to elucidate how deer habitat use and movement is related to that of coyotes and, ultimately, determine the presence of avoidance. Interactions between deer and coyotes were investigated using the statistical software R (R Development Core Team, 2018). We analyzed data of the study period (August 2017–July 2018) and between the fawning season and non-fawning season (April–August and September–March, respectively) to determine if avoidance was present overall and if avoidance was influenced by fawn presence. The 95% kernel density estimate home range was calculated for each deer and coyote during each of the temporal classes of interest (year, fawning, or non-fawning) using R package adehabitatHR (Calenge, 2015). To investigate shared use of space of coyotes and deer, area of overlap for the home ranges of each dyad was calculated. The proportion of home range overlap was used as an indicator of static interaction (Millspaugh et al. 2004).

To investigate dynamic interaction, we used the half-weight association index (HAI). This method uses the overlap area of two home ranges but includes temporal and spatial thresholds resulting in a more robust analysis of wildlife interaction (Long et al. 2014). The HAI focuses on the concurrent locations within the overlap area that are within proximity to each other. For our study, we used a spatial constraint of 200 meters as a measure of proximity. This spatial limit was chosen based on previous research finding that deer detected coyote presence generally at a distance of less than 200 meters (Lingle and Wilson 2001). HAI values near 0 suggest avoidance and values close to 1.0 suggest attraction within the overlap zone. Dynamic interaction analysis was conducted through the use of R package wildlifeDI (Long 2014).

RESULTS

Nineteen adult deer were captured in the 2016-2017 trapping season and 18 adult deer were captured during the 2017–2018 trapping season in Poplar Creek. Twenty-eight fawns were also captured over the duration of our study (14 in 2017; 14 in 2018). Ten coyotes were captured in the 2016–2017 trapping season and 16 coyotes were captured in the study area during the 2017–2018 trapping season. These coyotes and deer, in addition to the animals that were already collared in the study area, were considered for avoidance testing. Of these deer and coyotes, we chose to collect avoidance data on the individuals that primarily resided within the three designated study blocks. A total of 44 animals were chosen for avoidance testing: 22 deer (11 fawns, 11 adults) and 22 coyotes. Fifteen of the 22 coyotes and 17 of the 22 deer were captured during the 2016–2017 or 2017–2018 trapping seasons.

From August 2017 through July 2018, a total of 3,070 location data points were collected of the 44 animals selected for avoidance testing. Of these location data points, 1,014 were collected for avoidance analysis. Deer and coyotes caught before the start of this research or early during the collection period have a greater number of location data points than those captured later. Because of this, fawns captured in 2018 have a lower number of location data points than some of the other study animals. A few of our study animals (both deer and coyotes) died over the course of this collection period, resulting in fewer location data points for those animals as well.

For both static and dynamic interaction testing, deer-coyote dyads were developed within each study block (Table 5.1). Dyads were developed only if those individuals were both tracked for at least one distinct avoidance collection set. Only if simultaneous data was collected for a specific deer-coyote pairing was that dyad investigated for static and dynamic interaction for that study block. Study block 2 had the greatest number of dyads with 66 dyads, followed by study block 1 with 28 dyads and study block 3 with 4 dyads.

The average home range for deer was 1.36 km² and 14.9 km² for coyotes. Dyads including deer or coyotes that had less than five location points collected were excluded from analysis due to the inability to develop a reliable home range with less than five locations. This only happened with animals that died soon after capture (generally fawns). Of the 95 dyads which had enough location data points to delineate a home range, the proportion of area of overlap between the two home ranges varied. All dyads had home range overlap (example dyad in Figure 5.1). Proportion of overlap averaged 0.207 and ranged from 0.016–0.553. Furthermore, we developed core areas (50% kernel density estimate) for the deer and coyotes of each dyad to examine overlap of those areas. Over half (58.6%) of the dyads showed core area overlap, providing more evidence of shared usage of space. The average proportion of home range overlap between adult deer and fawns were found to be similar (0.203 and 0.213, respectively; two-sample t-test: $t = 0.33$, $P = 0.75$).

The dyads that had location data for both the fawning and non-fawning seasons were subjected to further overlap analysis between these two seasons. Average overlap during the fawning season was found to be less than the proportion overlap during the non-fawning season (0.186 and 0.234, respectively; two-sample t-test: $t = -1.94$, $P = 0.05$). Twenty-seven of the 42 dyads (64.3%) with adult deer saw a greater proportion of home range overlap during the non-fawning season. Nine of the 16 dyads (56.2%) with fawns saw an increase in proportion of home range overlap during the non-fawning season.

The results of the dynamic interaction analysis showed little simultaneous use of a shared area. When analyzing location data from the 2017–2018 study period collectively, the highest HAI result for the avoidance collection period was 0.091. Majority of the results were 0.0

(96.8%). When the data was divided by fawning and non-fawning season, there was little change in the HAI results. Four of the dyads experienced a higher HAI statistic during the non-fawning season than the fawning season. Three of these dyads showed a higher proportion of home range overlap in the non-fawning season while the other two dyads showed a higher proportion in the fawning season. One dyad showed a lower HAI result in the non-fawning season than the fawning season. This was accompanied by a larger proportion of home range overlap. The highest HAI result during the fawning season was 0.20 and the highest HAI result for the non-fawning season was 0.11.

DISCUSSION

Although home range overlap was observed in every dyad, the HAI results suggest fine-scale avoidance within shared areas throughout Poplar Creek. The results of the static and dynamic interaction analysis provide insight on how these two populations utilize the area. As expected, deer use the same areas as coyotes within Poplar Creek. This was confirmed through the static interaction analysis which showed home range overlap for every dyad. These results support our belief that the deer in Poplar Creek are not selecting areas absent of substantial coyote use. However, after investigating interaction at a finer-scale through dynamic interaction testing, close proximity avoidance was implied. These results indicate that the deer within Poplar Creek do not avoid the areas used by coyotes, but refrain from coming into close contact with coyotes.

When considering the static interaction results from the location data from the entire avoidance collection period, we would expect to see little difference in dynamic interaction between the adult deer and the fawns. The static interaction data of the fawning and non-fawning data, however, suggested that there may have been a difference in the dynamic interaction results between adult deer and fawns when comparing HAI results between those two seasons. After dynamic interaction analysis, we found that the dynamic interaction results between age classes when divided by fawning and non-fawning season provided no evidence of a pattern. These results indicate that age class does not influence the temporal avoidance of coyotes by deer in this population.

We did observe that certain deer, independent of what age class they belonged to, were more consistent than others to show an increase or decrease in proportion of home range overlap with the coyotes in their area between seasons. This suggests that shared usage of spaces with coyotes may differ between individual deer. Further research is needed to determine whether this pattern is observed in other populations and what factors influence spatial aversion to areas with coyotes by individual deer.

Our research adds valuable information to the limited literature that exists on the space-use of deer in high coyote density areas. Through the use of cameras and sign surveys, previous research found varied results on the avoidance of coyotes by deer. While some studies found a negative trend between coyote and deer presence (Waser et al. 2014, Jones et al. 2016), others found a positive correlation (Duquette et al. 2014, Magle et al. 2014, Pierce et al. 2015). Each of these studies took place in different geographical areas and habitats; some were done in urban/suburban areas (Magle et al. 2014, Jones et al. 2016) and others were in rural areas (Duquette et al. 2014, Waser et al. 2014, Pierce et al. 2015). One of these studies investigated the influence of coyote presence at varying scales (Pierce et al. 2015) and found results that complement our results. The Pierce et al. (2015) study, conducted in a rural area of New York, found that coyotes had little influence over deer browsing at the landscape scale but found that deer shifted to forest interiors in areas with greater indication of coyote presence. These results are similar to ours in that avoidance was observed only in specific instances: avoidance was only observed when examined at a fine scale. Further research is needed to determine what patterns exist and what factors influence the use of shared space between deer and coyotes.

MANAGEMENT IMPLICATIONS

The results of our study are likely of interest to managers in areas with concerns about the influence high coyote densities have on deer landscape-use. The results of our study imply that deer will still use the same areas as coyotes within high density areas, but that temporal usage of those areas may be influenced by coyote presence. Although not investigated in our study, temporal avoidance of specific areas has potential to impact the health of certain deer populations if there is movement away from preferred feeding areas due to coyote presence. This also has potential to influence when deer will be present in specific areas which, in addition to hunting pressure, can influence hunting success. Particularly, this information can be used by managers in areas with deer populations in poor health and in areas where hunting is implemented because there is potential for deer to utilize poor nutrition areas or non-hunting areas to avoid coyotes. Future research on the space-use of coyotes and deer within these areas are needed to understand how the relationship between these two species influences management concerns.

FIGURES AND TABLES

Table 5.1: Number of simultaneous locations and results of half-weight association index (HAI) statistic to measure dynamic interaction of deer-coyote dyads in Poplar Creek Forest Preserve in Hoffman Estates, Illinois (2017–2018). Home ranges (km²) and proportional area of home range overlap (AOP) is also shown for each dyad as a measure of static interaction.

Dyad							
Deer	Coyote	Age Class	Simultaneous Locations	HAI Result	Deer HR	Coyote HR	AOP
6	923	Adult	47	0	1.57	5.30	0.286
166	989	Fawn	47	0	1.56	4.09	0.365
60	987	Adult	46	0	0.71	4.12	0.164
138	919	Adult	46	0	2.48	22.28	0.112
138	923	Adult	46	0	2.48	5.30	0.392
166	987	Fawn	46	0	1.56	4.12	0.359
6	919	Adult	45	0	1.57	22.28	0.07
60	989	Adult	45	0	0.71	4.09	0.155
138	952	Adult	45	0	2.48	6.76	0.125
162	989	Fawn	45	0	1.53	4.09	0.327
6	1073	Adult	44	0	1.57	14.66	0.107
6	952	Adult	44	0	1.57	6.76	0.214
138	785	Adult	44	0	2.48	20.82	0.119
162	987	Fawn	44	0	1.53	4.12	0.306
138	1073	Adult	43	0	2.48	14.66	0.169
163	989	Fawn	43	0	1.78	4.09	0.372
6	785	Adult	42	0	1.57	20.82	0.075
163	987	Fawn	42	0	1.78	4.12	0.346
167	987	Fawn	42	0	1.64	4.12	0.394
167	989	Fawn	42	0	1.64	4.09	0.394
160	358	Fawn	36	0.03	1.51	1.97	0.508
160	904	Fawn	36	0	1.51	1.89	0.553
161	904	Fawn	36	0	0.59	1.89	0.253
161	358	Fawn	36	0	0.59	1.97	0.277
6	1072	Adult	31	0	1.57	53.37	0.029
138	1072	Adult	31	0	2.48	53.37	0.047
163	1054	Fawn	23	0	1.78	43.41	0.041
6	1086	Adult	22	0	1.57	8.87	0.176

Continued

Table 5.1 Continued

138	1086	Adult	22	0	2.48	8.87	0.223
60	1054	Adult	21	0.091	0.71	43.41	0.016
166	1054	Fawn	21	0	1.56	43.41	0.036
138	814	Adult	20	0	2.48	3.33	0.24
162	1054	Fawn	20	0.087	1.53	43.41	0.035
6	814	Adult	19	0	1.57	3.33	0.084
6	951	Adult	19	0	1.57	3.20	0.36
138	951	Adult	18	0	2.48	3.20	0.359
167	1054	Fawn	18	0	1.64	43.41	0.038
6	1162	Adult	16	0	1.57	7.81	0.191
6	1056	Adult	15	0	1.57	40.20	0.039
138	1056	Adult	15	0	2.48	40.20	0.062
138	1162	Adult	15	0	2.48	7.81	0.152
18	1181	Adult	12	0	0.94	3.78	0.198
18	987	Adult	12	0	0.94	4.12	0.21
54	1181	Adult	12	0	0.69	3.78	0.143
54	987	Adult	12	0	0.69	4.12	0.155
54	989	Adult	12	0	0.69	4.09	0.158
60	1181	Adult	12	0	0.71	3.78	0.183
61	1181	Adult	12	0	1.21	3.78	0.192
61	987	Adult	12	0	1.21	4.12	0.205
162	1181	Fawn	12	0	1.53	3.78	0.278
167	1181	Fawn	12	0	1.64	3.78	0.38
176	1181	Adult	12	0	2.44	3.78	0.525
181	1181	Adult	12	0	1.20	3.78	0.163
181	987	Adult	12	0	1.20	4.12	0.176
181	989	Adult	12	0	1.20	4.09	0.178
182	1181	Fawn	12	0	1.94	3.78	0.168
182	987	Fawn	12	0	1.94	4.12	0.19
6	1183	Adult	11	0	1.57	8.44	0.186
18	989	Adult	11	0	0.94	4.09	0.209
61	989	Adult	11	0	1.21	4.09	0.207
138	1183	Adult	11	0	2.48	8.44	0.252
166	1181	Fawn	11	0	1.56	3.78	0.341
176	987	Adult	11	0	2.44	4.12	0.5
182	989	Fawn	11	0	1.94	4.09	0.188
176	989	Adult	10	0	2.44	4.09	0.467
6	1082	Adult	9	0	1.57	11.61	0.097
138	1082	Adult	9	0	2.48	11.61	0.21
175	1181	Adult	7	0	0.94	3.78	0.153
175	987	Adult	7	0	0.94	4.12	0.166

Continued

Table 5.1 Continued

60	876	Adult	6	0	0.71	0.79	0.117
163	876	Fawn	6	0	1.78	0.79	0.098
163	874	Fawn	6	0	1.78	7.94	0.212
163	1181	Fawn	6	0	1.78	3.78	0.317
166	876	Fawn	6	0	1.56	0.79	0.144
175	989	Adult	6	0	0.94	4.09	0.173
183	989	Fawn	6	0	0.61	4.09	0.083
184	989	Fawn	6	0	0.48	4.09	0.11
184	987	Fawn	6	0	0.48	4.12	0.112
184	1181	Fawn	6	0	0.48	3.78	0.112
185	1181	Fawn	6	0	0.91	3.78	0.209
185	987	Fawn	6	0	0.91	4.12	0.22
185	989	Fawn	6	0	0.91	4.09	0.221
189	989	Fawn	6	0	0.21	4.09	0.046
189	987	Fawn	6	0	0.21	4.12	0.05
189	1181	Fawn	6	0	0.21	3.78	0.056
193	987	Fawn	6	0	0.61	4.12	0.147
193	989	Fawn	6	0	0.61	4.09	0.148
193	1181	Fawn	6	0	0.61	3.78	0.16
60	874	Adult	5	0	0.71	7.94	0.083
166	874	Fawn	5	0	1.56	7.94	0.196
183	1181	Fawn	5	0	0.61	3.78	0.064
183	987	Fawn	5	0	0.61	4.12	0.078
6	1158	Adult	4	0	1.57	53.80	0.029
138	1158	Adult	4	0	2.48	53.80	0.046

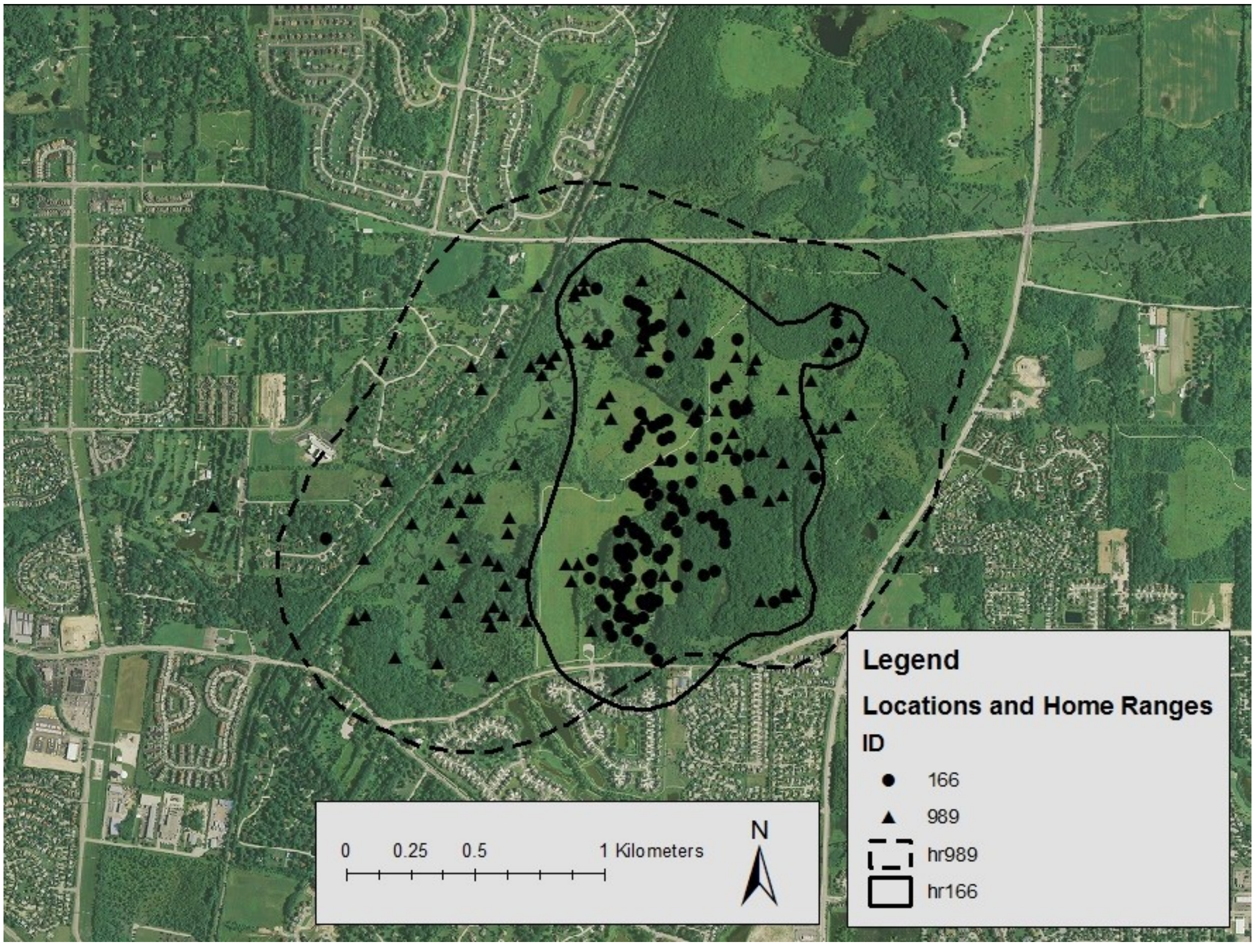

Figure 5.1: Locations and home ranges of coyote 989 and deer 166. This dyad is an example of the home range overlap observed between deer and coyotes in Poplar Creek Forest Preserve in Hoffman Estates, Illinois (2017–2018).

LITERATURE CITED

Calenge, C. 2015. adehabitatHR: home range estimation. R package. Version 0.4.14 [Cited 2018 October 20].

Doncaster, C.D. 1990. Non-parametric estimates of interaction from radio-tracking data. Journal of Theoretical Biology, 143:431-443.

Duquette, J.F., J.L. Belant, N.J. Svoboda, D.E. Beyer Jr., and P.E. Lederle. 2014. Effects of maternal nutrition, resource use and multi-predator risk on neonatal white-tailed deer survival. PLoS ONE, 9:e100841.

Etter, D., K., Hollis, T., Van Deelen, D., Ludwig, J., Chelsvig, C., Anchor, and R., Warner. 2002. Survival and Movements of White-Tailed Deer in Suburban Chicago, Illinois. The Journal of Wildlife Management, 66(2):500-510.

Gehrt, S. D., J. L. Brown, and C. Anchor. 2011. Is the urban coyote a misanthropic synanthrope? The case from Chicago. Cities and the Environment 4:Article 3.

Jones, B. M., M. V. Cove, M. A. Lashley, and V. L. Jackson. 2016. Do coyotes Canis latrans influence occupancy of prey in suburban forest fragments? Current Zoology 62:1–6.

Kilgo, J. C., H. S. Ray, M. Vukovich, M. J. Goode, and C. Ruth. 2012. Predation by coyotes on white-tailed deer neonates in South Carolina. The Journal of Wildlife Management 76(7):1420–1430.

Lingle, S. and W.F. Wilson. 2001. Detection and avoidance of predators in white-tailed deer (Odocoileus virginianus) and mule deer (O. hemionus). Ethology 107:125-147.

Long, J.A. 2014. wildlifeDI – A suite of R Tools for exploring dynamic interaction patterns in wildlife telemetry data. R Package Vignette. Version 0.2 [Cited 2018 October 20].

Long, J. A., T. A. Nelson, S. L. Webb, and K. L. Gee. 2014. A critical examination of indices of dynamic interaction for wildlife telemetry studies. Journal of Animal Ecology 83:1216-1233.

Macdonald, D.W., F.G. Ball, and N.G. Hough. 1980. The evaluation of home range size and configuration using radio tracking data. Pages 405-424 in C.J. Amlaner and D.W. MacDonald editors. A handbook on biotelemetry and radio tracking: proceedings of an international conference on telemetry and radio tracking in biology and medicine. Pergamon Press, Oxford.

Magle, S. B., L. S. Simoni, E. W. Lehrer, and J. S. Brown. 2014. Urban predator–prey association: coyote and deer distributions in the Chicago metropolitan area. Urban Ecosystems 17:875–891.

Morey, P. S., E. M. Gese, and S. D. Gehrt. 2007. Spatial and temporal variation in the diet of coyotes in the Chicago Metropolitan Area. The American Midland Naturalist 158:147–161.

Millspaugh, J.J., R.A. Gitzen, B.J. Kernohan, M.A. Larson, and C.L. Clay. 2004. Comparability of Three Analytical Techniques to Assess Joint Space Use. Wildlife Society Bulletin 32:148-157.

Nams, V. O. 2006. Locate III user's guide. Pacer Computer Software, Tatamagouche, Nova Scotia, Canada.

Newsome, S.D., H.M., Garbe, E.C., Wilson, and S.D., Gehrt. 2015. Individual variation in anthropogenic resource use in an urban carnivore. Oecologia 178:115–128.

Piccolo, B. P., T. R. Van Deelen, K. Hollis-Etter, D. R. Etter, R. E. Warner, and C. Anchor. 2010. Behavior and survival of white-tailed deer neonates in two suburban forest preserves. Canadian Journal of Zoology 88:487–495.

Pierce, J. L. B., S. A. Dalinsky, A. Chenaille, L. M. Lolya, J. L. Maguder, C. Mattilio, G. V. Mayhew, E. Regan, and D. A. Patrick. 2015. Scale-Dependent Effects of Coyote-Predation Risk on Patterns of White-Tailed Deer Browsing along Linear Forest Edges. Northeastern Naturalist 22:262–272.

R Development Core Team. 2018. R: A Language and Environment for Statistical Analysis. R Foundation for Statistical Computing, Vienna, Austria.

Sikes, R. S. 2016. Guidelines of the American Society of Mammalogists for the use of wild mammals in research and education. Journal of Mammalogy 97:663-688.

Waser, N. M., M. V. Price, D. T. Blumstein, S. Reneé Arózqueta, B. D. Castro Escobar, R. Pickens, and A. Pistoia. 2014. Coyotes, deer, and wildflowers: diverse evidence points to a trophic cascade. Naturwissenschaften 101:427–436.

Chapter 6: Influence of Coyotes on White-tailed Deer in a Suburban Forest Preserve in Chicago

As coyote (*Canis latrans*) populations continue to spread into metropolitan areas, their influence on the urban landscape will remain an interest to managers. Our study elucidated the impact of coyotes on white-tailed deer (*Odocoileus virginianus*) within a suburban forest preserve of the Chicago region, Poplar Creek. Although our project only studied the relationship of these two species within a single preserve, our results offer insight into how these two species interact within a human-dominated landscape. Furthermore, our study provides evidence that the specific relationship between two species may vary between urban and rural landscape types and that this specific relationship can impact the behaviors of those species. Ultimately, our study provides information on how the relationship between coyotes and white-tailed deer can influence which deer behaviors are shown and the severity in which they are expressed.

Through coyote scat analysis, we were able to determine that white-tailed deer are an important food source for coyotes in Poplar Creek. The consumption of deer by coyotes, however, was found to primarily occur in the summer months. Scats collected in the summer also frequently contained white-tailed deer remains that indicate fawn consumption (e.g. small hooves, ears). These results suggest that the arrival of fawns in May and June provide an important source of food for coyotes in the summer. Providing further support of this claim, the results of the fawn survival and mortality research allowed us to realize the prevalence of coyote predation on fawns at our study site. Survival of white-tailed deer fawns through the first year of life was fairly low and the most common cause of mortality was coyote predation. For some of the fawns, cause of mortality could not be definitively assigned between predation and other causes so our estimate of fawn predation by coyotes is a minimum estimate. Similar to other fawn studies, majority of coyote predation events occurred when fawns were less than two weeks old, a time during which fawns are primarily hiding in vegetation. After the first two weeks of life, incidents of coyote predation fell and fawns were more likely to survive. Combined, the results of the coyote diet analysis and fawn survival analyses support our belief that coyote predation on white-tailed deer within the study area is primarily focused on fawns.

The observed predation pattern of coyotes and white-tailed deer in our study area alludes to higher predation risk for fawns than adult white-tailed deer. Antipredator behaviors are influenced by predation risk and therefore, we expected the antipredator behaviors of white-tailed deer in our study area to reflect the age class specific predation risk. We predicted that white-tailed deer would not show signs of strong antipredator behavior in the presence or with indication of presence of coyotes and if they did, it would be exhibited by fawns or does with fawns. The results of the vigilance survey indicated that white-tailed deer in Poplar Creek do not alter vigilance when an indicator of coyotes, coyote urine, was present at the foraging site. Season was the only factor that showed some influence on vigilant behavior, but the statistical correlation was weak. The proportion of time spent vigilant while foraging was highest in the summer, when young fawns are present. The age class and sex of the deer foraging, however, was not shown to influence the proportion of time spent vigilant. The results of the vigilance survey indicate that white-tailed deer at this site do not change their antipredator behavior while foraging when a common indicator of coyote presence is within close proximity. Furthermore, the behavior of white-tailed deer when approaching the foraging site was found to be independent of the presence or absence of coyote urine. The age class of the approaching deer, group size of surrounding deer, and the season of video capture, however, were found to influence approach behavior suggesting that approach behavior was more effected by these factors than indication of coyote presence. These results suggest that white-tailed deer in Poplar Creek may be habituated to the presence of coyote urine or that this indicator of coyote presence is insufficient in yielding an antipredator response from this white-tailed deer population.

White-tailed deer and coyotes in Poplar Creek were also observed to have strong static interactions when surveying avoidance, another antipredator behavior. Through the use of radio-telemetry, we were able to determine that every collared coyote-deer dyad utilizing the same general areas within Poplar Creek exhibited home range overlap. These results suggest that the white-tailed deer at this site are not establishing home ranges that allow the complete avoidance of coyotes, thereby indicating that the predation risk is not great enough to elicit complete spatial avoidance. When examining dynamic interaction between these two species, however, avoidance was suggested for each dyad. These results suggest that although white-tailed deer are utilizing the same spaces as coyotes, they are not coming into close proximity to coyotes. The results of each of the conducted antipredator behavior surveys provide evidence that white-tailed deer in Poplar Creek will use the same areas as coyotes, and not change their behavior in response to the use of these areas by coyotes, but that they will avoid coming into close contact with them.

Previous research on the antipredator behavior of deer in response to coyotes is inconsistent in location, habitat, methods, and results. Our study, in addition to previous work, provides evidence that white-tailed deer behavior in response to coyotes is not homogenous across these species' range. The results of our study and previous work also suggest that the specific predator-prey relationship of these two species between sites can influence that behavioral response. Antipredator behavior is complex and can be influenced by a variety of factors. When predicting the antipredator behavior of white-tailed deer in response to coyotes, assumptions should not be made without investigation of the predator-prey relationship and the characteristics of the populations of these two species within the study area in question. Further research is needed to determine what factors are most influential in what antipredator behaviors are expressed and the severity of that expression by white-tailed deer. By continuing white-tailed deer antipredator behavior research, a greater understanding of the indirect effects of predation risk can be realized for this species. While further research is needed to better understand these effects, the results of our study provide valuable information on some of the impacts coyotes have on white-tailed deer behavior in an urban forest preserve.

References

Aher, A. M., D. Caudill, G. Caudill, R. S. Butryn, D. Wolf, M. Fox, D. P. Blake, and M. W. Cunningham. 2016. Prevalence, genetic analyses, and risk factors associated with heartworm (Dirofilaria immitis) in wild coyotes (Canis latrans) from Florida, USA. 2016. Journal of Wildlife Diseases 52:785-792.

Alexander, S. M., and M. S. Quinn. 2011. Coyote (Canis latrans) interactions with humans and pets reported in the Canadian print media (1995-2010). Human Dimensions of Wildlife 16:345-359.

Anderson, C. W., C. K. Nielsen, D. J. Storm, and E. M. Schauber. 2011. Modeling habitat use of deer in an exurban landscape. Wildlife Society Bulletin 35:161-167.

Atwood, T. C., H. P. Weeks, and T. M. Gehring. 2004. Spatial ecology of coyotes along a suburban-to-rural gradient. Journal of Wildlife Management 68:1000-1009.

Baker, R. O., and R. M. Timm. 2017. Coyote attacks on humans. 1970-2015: Implications for reducing the risks. Human-Wildlife Interactions 11:120-132.

Ballard, W. B. 2011. Impacts on ecosystems. Pages 251-286 in: D. G. Hewitt, editor. Biology and management of white-tailed deer. CRC Press, Boca Raton, Florida, USA.

Ballard, W. B., D. Lutz, T. W. Keegan, L. H. Carpenter, and J. C. deVos, Jr. 2001. Deer-predator relationships: A review of recent North American studies with emphasis on mule and black-tailed deer. Wildlife Society Bulletin 29:99-115.

Ballard, W. B., H. A. Whitlaw, S. J. Young, R. A. Jenkins, and G. J. Forbes. 1999. Predation and survival of white-tailed deer fawns in northcentral New Brunswick. Journal of Wildlife Management 63:574-579.

Barrette, C., and F. Messier. 1980. Scent-marking in free-ranging coyotes, *Canis latrans*. Animal Behavior 28:814–819.

Bates D., M. Maechler, B. Bolker, and S. Walker. 2018. Lme4: Linear mixed-effects models using Eigan and S4. R package version 1.1-18-1 [cited 2018 October 19].

Benson, J. F., K. M. Loveless, L. Y. Rutledge, and B. R. Patterson. 2017. Ungulate predation and ecological roles of wolves and coyotes in eastern North America. Ecological Applications 27:718-733.

Bombieri, G., M. M. Delgado, L. F. Russo, P. J. Garrote, J. V. López-Bao, J. M. Fedriani, and V. Penteriani. Patterns of wild carnivore attacks on humans in urban areas. Scientific Reports 8:17728.

Breck, S. W., S. A. Poessel, P. Mahoney, and J. K. Young. 2019. The intrepid urban coyote: a comparison of bold and exploratory behavior in coyotes from urban and rural environments. Scientific Reports 9:2104.

Brinkman, T. J., K. L., Monteith, J. A. Jenks, and C. S., Deperno. 2004. Predicting neonatal age of white-tailed deer in the northern Great Plains. The Prairie Naturalist 36:75-81.

Brown, J. S. 1999. Vigilance, patch use and habitat selection: foraging under predation risk. Evolutionary Ecology Research 1:49-71.

Brown, J. S., J. W. Laundré, and M. Gurung. 1999. The Ecology of Fear: Optimal Foraging, Game Theory, and Trophic Interactions. Journal of Mammalogy 80:385–399.

Burroughs, J. P., H. Campa III, S. R. Winterstein, B. A. Rudolph, and W. E. Moritz. 2006. Cause-specific mortality and survival of white-tailed deer fawns in southwestern lower Michigan. Journal of Wildlife Management 70:743-751.

Butfiloski, J. W., D. I. Hall, D. M. Hoffman, and D. L. Forster. 1997. White-tailed deer management in a coastal Georgia residential community. Wildlife Society Bulletin 25:491-495.

Calenge, C. 2015. adehabitatHR: home range estimation. R package. Version 0.4.14 [Cited 2018 October 20].

Carstensen, M., G. D. DelGiudice, and B. A., Sampson. 2003. Using doe behavior and vaginal-implant transmitters to capture neonate white-tailed deer in north-central Minnesota. Wildlife Society Bulletin 31:634–641.

Carstensen, M., G. D. DelGiudice, B. A. Sampson, and D. W. Kuehn. 2009. Survival, birth characteristics, and cause-specific mortality of white-tailed deer neonates. Journal of Wildlife Management 73:175-183.

Cepek, J. D. 2004. Diet composition of coyotes in the Cuyahoga Valley National Park, Ohio. Ohio Journal of Science 104:60-64.

Champagne, E., L. Perroud, A. Dumont, J. –P. Tremblay, and S. D. Côté. 2018. Neighboring plants and perception of predation risk modulate winter browsing by white-tailed deer (Odocoileus virginianus). Canadian Journal of Zoology 92:117-125.

Cherry, M. J., L. M. Conner, and R. J. Warren. 2015. Effects of predation risk and group dynamics on white-tailed deer foraging behavior in a longleaf pine savanna. Behavioral Ecology arv054. doi:10.1093/beheco/arv054.

Cherry, M. J., K. E. Morgan, B. T. Rutledge, L. M. Conner, and R. J. Warren. 2016*a*. Can coyote predation risk induce reproduction suppression in white-tailed deer? Ecosphere 7(10): e01481.

Cherry, M. J., K. L. Turner, M. B. Howze, B. S. Cohen, and L. M. Conner. 2016*b*. Coyote diets in a longleaf pine ecosystem. Wildlife Biology 22:64–70.

Chitwood, M. C., M. A. Lashley, C. E. Moorman, and C. S. DePerno. 2014. Confirmation of coyote predation on adult female white-tailed deer in the southeastern United States. Southeastern Naturalist 13:N30-N32.

Chitwood, M. C., M. A. Lashley, C. S. DePerno, and C. E. Moorman. 2017. Considerations on neonatal ungulate capture method: potential for bias in survival estimation and cause-specific mortality. Wildlife Biology 2017:wlb.00250.

Chitwood, M. C., M. A. Lashley, C. E. Moorman, and C. S. DePerno. 2017. Setting an evolutionary trap: could the hider strategy be maladaptive for white-tailed deer? Journal of Ethology 35:251-257.

Clinchy, M., M. J. Sheriff, and L. Y. Zanette. 2013. Predator-induced stress and the ecology of fear. Functional Ecology 27:56-65.

Cook, R. S., M. White, D. O. Trainer, and W. C. Glazener. 1971. Mortality of young white-tailed deer fawns in south Texas. Journal of Wildlife Management 35:47-56.

Crawford, J. C., A. Dechen Quinn, D. M. Williams, B. A. Rudolph, K. T. Scribner, and W. F. Porter. 2018. Fine-scale spatial genetic structure of deer in a suburban landscape. Journal of Wildlife Management 82:596-607.

Crête, M., J. –P. Ouellet. J. –P. Tremblay, and R. Arsenault. 2001. Suitability of the forest landscape for coyotes in northeastern North America and its implications for coexistence with other carnivores. Écoscience 8:311-319.

Crimmins, S. M., J. W. Edwards, and J. M. Houben. 2012. *Canis latrans* (coyote) habitat use and feeding habits in central West Virginia. Northeastern Naturalist 19:411-420.

Debelica A., and M. L. Thies. 2009. Atlas and key to the hair of terrestrial Texas mammals. Special Publications of the Museum of Texas Tech University, Number 55.

DeNicola, A. J., D. J. Kesler, and R. K. Swihart. 1997. Remotely delivered prostaglandin F(2α) implants terminate pregnancy in white-tailed deer. Wildlife Society Bulletin 25:527-531.

DeNicola, A. J., K. C. VerCauteren, P. D. Curtis, and S. E. Hygnstrom. 2000. Managing white-tailed deer in suburban environments: a technical guide. Cornell Cooperative Extension Information Bulletin, Cornell University, Ithaca, New York, USA.

DePerno, C. S., J. A. Jenks, S. L. Griffin, and L. A. Rice. 2000. Female survival rates in a declining white-tailed deer population. Wildlife Society Bulletin 28:1030-1037.

Ditchkoff, S. S., S. T. Saalfeld, and C. J. Gibson. 2006. Animal behavior in urban ecosystems: Modifications due to human-induced stress. Urban Ecosystems 9:5–12.

Doncaster, C.D. 1990. Non-parametric estimates of interaction from radio-tracking data. Journal of Theoretical Biology, 143:431-443.

Donohue, R. N., D. G. Hewitt, T. E. Fulbright, C. A. Deyoung, A. R. Litt, and D. A. Draeger. 2013. Aggressive behavior of white-tailed deer at concentrated food sites as affected by population density. Journal of Wildlife Management 77:1401-1408.

Duquette, J. F., J. L. Belant, N. J. Svoboda, D. E. Beyer Jr., P. E. Lederle. 2014. Effects of maternal nutrition, resource use and multi-predator risk on neonatal white-tailed deer survival. PLoS ONE 9(6):e100841.

Etter, D., K. Hollis, T. Van Deelen, D. Ludwig, J. Chelsvig, C. Anchor, and R. Warner. 2002. Survival and movements of white-tailed deer in suburban Chicago, Illinois. Journal of Wildlife Management 66:500-510.

Fedriani, J. M., T. K. Fuller, and R. M. Sauvajot. 2001. Does availability of anthropogenic food enhance densities of omnivorous mammals? An example with coyotes in southern California. Ecography 24:325-331.

Ferrero, D. M. J. K. Lemon, D. Fluegge, S. L. Pashkovski, W. J. Korzan, S. R. Datta, M. Spehr, M. Fendt, and S. D. Liberles. 2011. Detection and avoidance of a carnivore odor by prey. Proceedings of the National Academy of Sciences of the United States of America 108:11235-11240.

Gallo, T., M. Fidino, E. W. Lehrer, and S. B. Magle. 2017. Mammal diversity and metacommunity dynamics in urban green spaces: Implications for urban wildlife conservation. Ecological Applications 27:2330-2341.

Garrott, R. A. 1995. Effective management of free-ranging ungulate populations using contraception. Wildlife Society Bulletin 23:445-452.

Gehrt, S. D. 2007. Ecology of Coyotes in Urban Landscapes. Pages 303-311. Proceedings of the 12th Wildlife Damage Management Conference, Corpus Christi, Texas.

Gehrt, S. D., C. Anchor, and L. A. White. 2009. Home range and landscape use of coyotes in a metropolitan landscape: Conflict or coexistence? Journal of Mammalogy 90:1045-1057.

Gehrt, S. D., J. L. Brown, and C. Anchor. 2011. Is the urban coyote a misanthropic synanthrope? The case from Chicago. Cities and the Environment 4:Article 3.

Gehrt, S. D., and S. P. D. Riley. 2010. Coyotes (Canis latrans). In: Gehrt SD, Riley SPD, Cypher BL (eds) Urban carnivores: ecology, conflict, and conservation. Johns Hopkins University Press, Baltimore, Maryland, USA pp 79–95.

Gese, E. M., P. S. Morey, and S. D. Gehrt. 2012. Influence of the urban matrix on space use of coyotes in the Chicago metropolitan area. Journal of Ethology 30:413-425.

Gilman, R. T., N. E. Mathews, B. G. Skinner, V. L. Julis, A. S. Frank, and J. Paul-Murphy. 2010. Effects of maternal status on the movement and mortality of sterilized female white-tailed deer. Journal of Wildlife Management 74:1484-1491.

Gingery T. M., D. R. Diefenbach, B. D. Wallingford, and C. S. Rosenberry. 2018. Landscape-level patterns in fawn survival across North America. Journal of Wildlife Management 82:1003-1013.

Greenspan, E., C. K. Nielsen, and K. W. Cassel. 2018. Potential distribution of coyotes (Canis latrans), Virginia opossums (Didelphis virginiana), striped skunks (Mephitis mephitis), and raccoons (Procyon lotor) in the Chicago Metropolitan Area. Urban Ecosystems 21:983-997.

Grigione, M. M., P. Burman, S. Clavio, S. J. Harper, D. L. Manning, and R. J. Sarno. 2011. Diet of Florida coyotes in an protected wildland and suburban habitat. Urban Ecosystems 14:655-663.

Grigione, M. M., P. Burman, S. Clavio, S. J. Harper, D. L. Manning, and R. J. Sarno. 2014. A comparative study between enteric parasites if coyotes in a protected and suburban habitat. Urban Ecosystems 17:1-10.

Grovenburg, T. W., R. W. Klaver, and J. A. Jenks. 2012. Survival of white-tailed deer fawns in the grasslands of the northern Great Plains. Journal of Wildlife Management 76:944-956.

Grovenburg, T. W., C. C. Swanson, C. N. Jacques, R. W. Klaver, T. J. Brinkman, B. M. Burris, C. S. Deperno, and J. A. Jenks. 2011. Survival of white-tailed deer neonates in Minnesota and South Dakota. Journal of Wildlife Management 75:213-220.

Grund, M. D., J. B. McAninch, and E. P. Wiggers. 2002. Seasonal movements and habitat use of female white-tailed deer associated with an urban park. Journal of Wildlife Management 66:123-130.

Gulsby, W. D., M. J. Cherry, J. T. Johnson, L. M. Connor, and K. V. Miller. 2018. Behavioral response of white-tailed deer to coyote predation risk. Ecosphere 9:e02140.

Gulsby, W. D., C. H. Killmaster, J. W. Bowers, J. D. Kelly, B. N. Sacks, M. J. Statham, and K. V. Miller. 2015. White-tailed deer fawn recruitment before and after experimental coyote removals in central Georgia. Wildlife Society Bulletin 39:248-255.

Hasapes, S. K., and C. E. Comer. 2017. White-tailed deer fawn survival, home range, and habitat composition in northwest Louisiana. Wildlife Society Bulletin 41:499-507.

Haugen, A. O., and D. W. Speake. 1958. Determining age of young fawn white-tailed deer. Journal of Wildlife Management 22:319-320.

Henderson, D. W., R. J. Warren, J. A. Cromwell, and R. J. Hamilton. 2000. Responses of urban deer to a 50% reduction in local herd density. Wildlife Society Bulletin 28:902-910.

Hildreth, M. B., D. S. Blunt, and J. A. Oaks. 2004. Lethal effects of freezing *Echinococcus multilocularis* eggs at ultralow temperatures. Journal of Parasitology 90:841-844.

Hildreth, A. M., S. E. Hygnstrom, and K. C. VerCauteren. 2013. Deer-activated bioacoustics frightening device deters white-tailed deer. Human-Wildlife Interactions 7:107-113.

Hinton, J. W., A. K. Ashley, J. A. Dellinger, J. L. Gittleman, F. T. Van Manen, and M. J. Chamberlain. 2017. Using diets of Canis breeding pairs to assess resource partitioning between sympatric red wolves and coyotes. Journal of Mammalogy 98:475-488.

Honda, T., H. Iijima, J. Tsuboi, and K. Uchida. 2018. A review of urban wildlife management from the animal personality perspective: The case of urban deer. Science of the Total Environment 644:576-582.

Huegel, C. N., and O. J. Rongstad. 1985. Winter foraging patterns and consumption rates of northern Wisconsin coyotes. American Midland Naturalist 113:203-207.

Jackson, A. M., and S. S. Ditchkoff. 2013. Survival estimates of white-tailed deer fawns at Fort Rucker, Alabama. American Midland Naturalist 170:184-190.

Jackson, R. M., M. White, and F. F. Knowlton. 1972. Activity patterns of young white-tailed deer fawns in south Texas. Ecology 53:262-270.

Jones, B. M., M. V. Cove, M. A. Lashley, and V. L. Jackson. 2016. Do coyotes Canis latrans influence occupancy of prey in suburban forest fragments? Current Zoology 62:1–6.

Kavaliers, M. and E. Choleris. 2001. Antipredator responses and defensive behavior: ecological and ethological approaches for the neurosciences. Neuroscience & Biobehavioral Reviews 25:577–586.

Kennedy, S. I. 2015. White-tailed deer (*Odocoileus virginianus*) fawn survival and seasonal patterns of white-tailed deer and coyotes (*Canis latrans*) in the Cleveland metropolitan area. Thesis, The Ohio State University, Columbus, USA.

Kilgo, J. C., H. S. Ray, M. Vukovich, M. J. Goode, and C. Ruth. 2012. Predation by coyotes on white-tailed deer neonates in South Carolina. Journal of Wildlife Management 76:1420–1430.

Kilgo, J. C., M. Vukovich, M. J. Conroy, H. S. Roy, and C. Ruth. 2016. Factors affecting survival of adult female white-tailed deer after coyote establishment in South Carolina. Wildlife Society Bulletin 40:747-753.

Kilgo, J. C., M. Vukovich, H. S. Ray, C. E. Shaw, and C. Ruth. 2014. Coyote removal, understory cover, and survival of white-tailed deer neonates. Journal of Wildlife Management 78:1261-1271.

Kilpatrick, H. J., A. M. Labone, and J. S. Barclay. 2007. Acceptance of deer management strategies by suburban homeowners and bowhunters. Journal of Wildlife Management 71:2095-2101.

Kilpatrick, H.J., and K. K. Lima. 1999. Effects of archery hunting on movement and activity of female white-tailed deer in an urban landscape. Wildlife Society Bulletin 27:433-440.

Kilpatrick, H. J., and S. M. Spohr. 2000. Spatial and temporal use of a suburban landscape by female white-tailed deer. Wildlife Society Bulletin 28:1023-1029.

Kilpatrick, H. J., S. M. Spohr, and K. K. Lima. 2001. Effects of population reduction on home ranges of female white-tailed deer at high densities. Canadian Journal of Zoology 79:949-954.

Klare, U., J. F. Kamler, and D. W. Macdonald. 2011. A comparison and critique of different scat-analysis methods for determining carnivore diet. Mammal Review 41:294-312.

Klein, C., S. Barua, S. Liccioli, and A. Massolo. 2019. Neospora caninum DNA in coyote fecal samples collected in an urban environment. Journal of Wildlife Diseases 55:196-199.

Larson, R. N., D. J. Morin, I. A. Wierzbowska, and K. R. Crooks. 2015. Food habits of coyotes, gray foxes, and bobcats in a coastal southern California urban landscape. Western Northern American Naturalist 75:339-347.

Lashley, M. A., M. C. Chitwood, M. T. Biggerstaff, D. L. Morina, C. E. Moorman, and C. S. DePerno. 2014. White-tailed deer vigilance: The influence of social and environmental factors. PLoS ONE 9(3):e90652.

Laundré, J. W., L. Hernández, and W. J. Ripple. 2010. The landscape of fear: Ecological implications of being afraid. The Open Ecology Journal 3:1-7.

Liccioli, S., C. Bialowas, K. E. Ruckstuhl, and A. Massolo. 2015. Feeding ecology informas parasite epidemiology: prey selection modulates encounter rate with Echinococcus multilocularis in urban coyotes. PLoS ONE 10:e0121646.

Lima, S. L. 1998. Nonlethal Effects in the Ecology of Predator-Prey Interactions. BioScience 48:25–34.

Lima, S. L., and P. A. Bednekoff. 1999. Temporal variation in danger drives antipredator behavior: the predation risk allocation hypothesis. The American Naturalist 153:649-659.

Lingle, S. 2000. Seasonal variation in coyote feeding and mortality of white-tailed deer and mule deer. 2000. Canadian Journal of Zoology 78:85-99.

Lingle, S. 2001. Anti-predator strategies and grouping patterns in white-tailed deer and mule deer. Ethology 107:295-314.

Lingle, S., and W. F. Wilson. 2001. Detection and avoidance of predators in white-tailed deer (Odocoileus virginianus) and mule deer (O. hemionus). Ethology 107:125-147.

Lombardi, J. V., C. E. Comer, D. G. Scognamillo, and W. C. Conway. 2017. Coyote, fox, and bobcat response to anthropogenic and natural landscape features in a small urban area. Urban Ecosystems 20:1239-1248.

Long, J.A. 2014. wildlifeDI – A suite of R Tools for exploring dynamic interaction patterns in wildlife telemetry data. R Package Vignette. Version 0.2 [Cited 2018 October 20].

Long, J. A., T. A. Nelson, S. L. Webb, and K. L. Gee. 2014. A critical examination of indices of dynamic interaction for wildlife telemetry studies. Journal of Animal Ecology 83:1216-1233.

Long, R. A., A. F. O'Connell, and D. J. Harrison. 1998. Mortality and survival of white-tailed deer (*Odocoileus virginianus*) fawns on a north Atlantic coastal island. Wildlife Biology 4:237-247.

Lukasik, V. M., and S. M. Alexander. 2012. Spatial and temporal variation of coyote (*Canis latrans*) diet in Calgary, Alberta. Cities and the Environment 4: Article 8.

MacCracken, J. G., and D. W., Uresh. 1984. Coyote foods in the Black Hills, South Dakota. The Journal of Wildlife Management 48:1420–1423.

Macdonald, D.W., F.G. Ball, and N.G. Hough. 1980. The evaluation of home range size and configuration using radio tracking data. Pages 405-424 in C.J. Amlaner and D.W. MacDonald editors. A handbook on biotelemetry and radio tracking: proceedings of an international conference on telemetry and radio tracking in biology and medicine. Pergamon Press, Oxford.

Magle, S. B., L. S. Simoni, E. W. Lehrer, and J. S. Brown. 2014. Urban predator–prey association: coyote and deer distributions in the Chicago metropolitan area. Urban Ecosystems 17:875–891.

McCance, E. C., R. K. Baydeck, D. J. Walker, and D. N. Leask. 2015. Spatial and temporal analysis of factors associated with urban deer-vehicle collisions. Human-Wildlife Interactions 9:119-131.

McCance, E. C., M. M. Campbell, and R. K. Baydeck. 2015. White-tailed deer movement patterns in a Canadian metropolitan area. Human Dimensions of Wildlife 20:471-483.

McCoy, J. C., S. S. Ditchkoff, J. B. Raglin, B. A. Collier, and C. Ruth. 2013. Factors influencing survival of white-tailed deer in coastal South Carolina. Journal of Fish and Wildlife Management 4:280-289.

Messier, F., C., Barrette, and J., Huot. 1986. Coyote predation on a white-tailed deer population in southern Quebec. Canadian Journal of Zoology 64:1134–1136.

Messmer, T. A., S. M. George, and L. Cornicelli. 1997. Legal considerations regarding lethal and nonlethal approaches to managing urban deer. Wildlife Society Bulletin 25:424-429.

Millspaugh, J.J., R.A. Gitzen, B.J. Kernohan, M.A. Larson, and C.L. Clay. 2004. Comparability of Three Analytical Techniques to Assess Joint Space Use. Wildlife Society Bulletin 32:148-157.

Mitchell, N., M. W. Strohbach, R. Pratt, W. C. Finn, and E. G. Strauss. 2015. Space use by resident and transient coyotes un an urban-rural landscape mosaic. Wildlife Research 42:461-469.

Moll, R. J., J. D. Cepek, P. D. Lorch, P. M. Dennis, T. Robison, J. J. Millspaugh, and R. A. Montgomery. 2018. Humans and urban development mediate the sympatry of competing carnivores. Urban Ecosystems 21:765-778.

Moratz, K. L., B. S. Gullikson, E. S. Michel, J. A. Jenks, D. M. Grove, and W. F. Jensen. 2018. Assessing factors affecting adult female white-tailed deer survival in the Northern Great Plains. Wildlife Research 45:679-684.

Morey, P. S., E. M. Gese, and S. D. Gehrt. 2007. Spatial and temporal variation in the diet of coyotes in the Chicago Metropolitan Area. The American Midland Naturalist 158:147–161.

Mumma, M. A., J. R. Adams, C. Zieminski, T. K. Fuller, S. P. Mahoney, and L. P. Waits. 2016. A comparison of morphological and molecular diet analyses of predator scats. Journal of Mammalogy 97:112-120.

Murray, M. H., A. Cembrowski, A. D. M. Latham, V. M. Lukasik, S. Pruss, and C. C. St. Clair. 2015. Greater consumption of protein-poor anthropogenic food by urban relative to rural coyotes increases diet breadth and potential for human-wildlife conflict. Ecography 38:1235-1242.

Murray, M. H., and C. C. St. Clair. 2017. Predictable features attract urban coyotes to residential yards. Journal of Wildlife Management 81:593-600.

Nams, V. O. 2006. Locate III user's guide. Pacer Computer Software, Tatamagouche, Nova Scotia, Canada.

Nelson, T. A., and A. Woolf. 1987. Mortality of white-tailed deer fawns in southern Illinois. Journal of Wildlife Management 51:326-329.

Newsome, S. D., H. M. Garbe, E. C. Wilson, and S. D. Gehrt. 2015. Individual variation in anthropogenic resource use in an urban carnivore. Oecologia 178:115-128.

Nixon, C. M., L. P. Hansen, P. A. Brewer, and J. E. Chelsvig. 1991. Ecology of white-tailed deer in an intensively farmed region of Illinois. Wildlife Monographs 118:3-77.

O'Gara, B. W., and R. B. Harris. 1988. Age and condition of deer killed by predators and coyotes. Journal of Wildlife Management 52:316-320.

Patterson, B. R., L. K. Benjamin, and F. Messier. 1998. Prey switching and feeding habits of eastern coyotes in relation to snowshoe hare and white-tailed deer densities. Canadian Journal of Zoology 76:1885-1897.

Patterson, B. R. and F. Messier. 2003. Age and condition of deer killed by coyotes in Nova Scotia. Canadian Journal of Zoology 81:1894-1898.

Patterson, B. R. and F. Messier. 2001. Social organization and space use of coyotes in eastern Canada relative to prey distribution and abundance. Journal of Mammalogy 82:463-477.

Périquet S., L. Todd-Jones, M. Valeix, B. Stapelkamp, N. Elliot, M. Wijers, O. Pays, D. Fortin, H. Madzikanda, H. Fritz, D. W. Macdonald, and A. J. Loveridge. 2012. Influence of immediate predation risk by lions on the vigilance of prey of different body size. Behavioral Ecology 23:970-976.

Petroelje, T. R., J. L. Belant, D. E. Beyer Jr., G. Wang, and B. D. Leopold. 2014. Population-level response of coyotes to a pulsed resource event. Population Ecology 56:349-358.

Piccolo, B. P., T. R. Van Deelen, K. Hollis-Etter, D. R. Etter, R. E. Warner, and C. Anchor. 2010. Behavior and survival of white-tailed deer neonates in two suburban forest preserves. Canadian Journal of Zoology 88:487–495.

Pierce, J. L. B., S. A. Dalinsky, A. Chenaille, L. M. Lolya, J. L. Maguder, C. Mattilio, G. V. Mayhew, E. Regan, and D. A. Patrick. 2015. Scale-dependent effects of coyote-predation risk on patterns of white-tailed deer browsing along linear forest edges. Northeastern Naturalist 22:262–272.

Poessel, S. A., S. W. Breck, and E. M. Gese. 2016. Spatial ecology of coyotes in the Denver metropolitan area: Influence of the urban matrix. Journal of Mammalogy 97:1414-1427.

Poessel, S. A., E. M. Gese, and J. K. Young. 2017. Environmental factors influencing the occurrence of coyotes and conflicts in urban areas. Landscape and Urban Planning 157:259-269.

Poessel, S. A., E. C. Mock, and S. W. Breck. 2017. Coyote (*Canis latrans*) diet in an urban environment: variation relative to pet conflicts, housing density, and season. Canadian Journal of Zoology 95:287-297.

Porter, W. F., H. B. Underwood, and J. L. Woodard. 2004. Movement behavior, dispersal, and the potential for localized management of deer in a suburban environment. Journal of Wildlife Management 68:247-256.

Quinn, T. 1997. Coyote (Canis latrans) food habits in three urban habitat types of western Washington. Northwest Science 71:1-5.

R Development Core Team. 2018. R: a language and environment for statistical computing. Vienna (Austria): R Foundation for Statistical Computing [cited 2018 October 19].

Randa, L. A., D. M. Cooper, P. L. Meserve, and J. A. Yunger. 2009. Prey switching of sympatric canids in response to variable prey abundance. Journal of Mammalogy 90:594-603.

Rawson, R. E., G. D. DelGiudice, H. E. Dziuk, and L. D. Mech. 1992. Energy metabolism and hematology of white-tailed deer fawns. Journal of Wildlife Diseases 28:91-94.

Richardson, K. E. and F. W. Weckerly. 2007. Intersexual social behavior of urban white-tailed deer and its evolutionary implications. Canadian Journal of Zoology 85:759-766.

Robinson, H. S., R. B. Wielgus, and J. C. Gwilliam. 2002. Cougar predation and population growth of sympatric mule deer and white-tailed deer. Canadian Journal of Zoology 80:556–568.

Rohm, J. H., C. K. Nielsen and A. Woolf. 2007. Survival of white-tailed deer fawns in southern Illinois. Journal of Wildlife Management 71:851–860.

Saalfeld S. T. and S. S. Ditchkoff. 2007. Survival of neonatal white-tailed deer in an exurban population. The Journal of Wildlife Management 71:940-944.

Sams, M., R., Lochmiller, E., Hellgren, W., Warde, and L., Varner. 1996. Morphometric predictors of neonatal age for white-tailed deer. Wildlife Society Bulletin 24:53-57.

Santana, E. and J. Armstrong. 2017. Food habits and anthropogenic supplementation in coyote (Canis latrans) diets along an urban-rural gradient. Human-Wildlife Interactions 11:156-166.

Schrecengost, J. D., J. C. Kilgo, D. Mallard, S. Ray, and K. V. Miller. 2008. Seasonal food habits of the coyote in the South Carolina coastal plain. Southeastern Naturalist 7:135-144.

Schuttler, S. G., A. W. Parsons, T. D. Forrester, M. C. Baker, W. J. McShea, R. Costello, and R. Kays. 2017. Deer on the lookout: how hunting, hiking and coyotes affect white-tailed deer vigilance. Journal of Zoology 301:320-327.

Seamans, T. W., B. F. Blackwell, and J. D. Cepek. 2002. Coyote hair as an area repellent for white-tailed deer. International Journal of Pest Management, 48:4, 301-306.

Seamans, T. W., B. F. Blackwell, and K. E. Linnell. 2016. Use of predator hair to enhance perceived risk to white-tailed deer in a foraging context. Human-Wildlife Interactions 10:300-311.

Shuman, R. M, M. J. Cherry, T. N. Simoneaux, E. A. Dutoit, J. C. Kilgo, M. J. Chamberlain, and K.V. Miller. 2017. Survival of white-tailed deer neonates in Louisiana. Journal of Wildlife Management 81:834-845.

Sikes, R. S. 2016. Guidelines of the American Society of Mammalogists for the use of wild mammals in research and education. Journal of Mammalogy 97:663-688.

Steiner, W., F. Leisch, and K. Hackländer. 2014. A review on the temporal pattern of deer-vehicle accidents: Impacts of seasonal, diurnal and lunar effects in cervids. Accident Analysis and Prevention 66:168-181.

Stone, D. B., M. J. Cherry, J. A. Martin, B. S. Cohen, and K. V. Miller. 2017. Breeding chronology and social interactions affect ungulate foraging behavior at a concentrated food source. PLoS ONE 12:e0178477.

Storm, D. J., C. K. Nielsen, E. M. Schauber, and A. Woolf. 2007. Space use and survival of white-tailed deer in an exurban landscape. The Journal of Wildlife Management, 71:1170–1176.

Stout, R. J., R. C. Stedman, D. J. Decker, and B. A. Knuth. 1993. Perceptions of risk from deer-related vehicle accidents: implications for public preferences for deer herd size. Wildlife Society Bulletin 21:237-249.

Sutton, N. M. and E. J. Heske. 2017. Effects of human state park visitation rates on escape behavior of white-tailed deer. Human-Wildlife Interactions 11:86-98.

Swihart, R. K., P. M. Picone, A. J. DeNicola, and L. Cornicelli. 1995. Ecology of urban and suburban white-tailed deer. In: McAninch JB (ed) Urban deer: a manageable resource? 1993 Symposium of the North Central Section. The Wildlife Society, St. Louis, Missouri, USA pp 35-44.

Swihart, R. K., J. J. Pignatello, and M. J. I. Mattina. 1991. Aversive responses of white-tailed deer, Odocoileus virginianus, to predator urines. Journal of Chemical Ecology 17:767–777.

Swingen, M. B., C. S. DePerno, and C. E. Moorman. 2015. Seasonal coyote diet composition at a low-productivity site. Southeastern Naturalist 14:397-404.

Telford, S. R., T. N., Mather, S. I., Moore, M. L., Wilson, and A., Spielman. 1988. Incompetence of deer as reservoirs of the Lyme disease spirochete. American Journal of Tropical Medicine and Hygiene 39:105–109.

Townsend, T. W. and E. D. Bailey. 1981. Effects of age, sex and weight on social rank in penned white-tailed deer. American Midland Naturalist 106:92-101.

Turner, M. M., A. P. Rockhill, C. S. Deperno, J. A. Jenks, R. W. Klaver, A. R. Jarding, T. W. Grovenburg, and K. H. Pollock. 2011. Evaluating the effect of predators on white-tailed deer: Movement and diet of coyotes. Journal of Wildlife Management 75:905-912.

United States Census Bureau. 2018. Quick Facts: Cook County, Illinois. Retrieved from http://www.census.goc/quickfacts/fact/table/cookcountyillinois/PST120217.

United States Climate Data. 2018. Climate: Chicago-Illinois. Retrieved from https://www.usclimatedata.com/climate/chicago/illinois/united-states/usil0225.

Urbanek, R. E. and C. K. Nielsen. 2013. Influence of landscape factors on density of suburban white-tailed deer. Landscape and Urban Planning 114:28-36.

VerCauteren, K. C. 2003. The deer boom: Discussions on the population growth and range expansion of the white-tailed deer. USDA National Wildlife Research Center-Staff Publications 281.

VerCauteren, K. C., J. A. Shivik, and M. J. Lavelle. 2005. Efficacy of an animal-activated frightening device on urban elk and mule deer. Wildlife Society Bulletin 33:1282-1287.

Verme, L. J., and D. E. Ullrey. 1984. Physiology and nutrition. Pages 91-118 in L.K. Halls, editor. White-tailed deer ecology and management. Stackpole, Harrisburg, Pennsylvania, USA.

Vreeland, J.K., D. R. Diefenbach, and B. D. Wallingford. 2004. Survival rates, mortality causes, and habitats of Pennsylvania white-tailed deer fawns. Wildlife Society Bulletin 32:542-553.

Waller, D. M., and W. S. Alverson. 1997. The white-tailed deer: a keystone herbivore. Wildlife Society Bulletin 25:217–226.

Walter, W. D., J. Beringer, L. P. Hansen, J. W. Fischer, J. J. Millspaugh, and K. C. VerCauteren. 2011. Factors affecting space use overlap by white-tailed deer in an urban landscape. International Journal of Geographical Information Science 25:379-392.

Walter, W. D., K. C. VerCauteren, H. Campa III, W. R. Clark, J. W. Fischer, S. E. Hygnstrom, N. E. Mathews, C. K. Nielsen, E. M. Schauber, T. R. Van Deelen, and S. R. Winterstein. 2009. Regional assessment on influence of landscape configuration and connectivity on range size of white-tailed deer. Landscape Ecology 24:1405-1420.

Ward, J. N., J. W. Hinton, K. L. Johannsen, M. L. Karlin, K. V. Miller, and M. J. Chamberlain. 2018. Home range size, vegetation density, and season influences prey use by coyotes (Canis latrans). PLoS ONE 13(10): e0203703.

Waser, N. M., M. V. Price, D. T. Blumstein, S. Reneé Arózqueta, B. D. Castro Escobar, R. Pickens, and A. Pistoia. 2014. Coyotes, deer, and wildflowers: diverse evidence points to a trophic cascade. Naturwissenschaften 101:427–436.

Way, J. G. 2007. Movements of transient coyotes, Canis latrans, in urbanized eastern Massachusetts. Canadian Field-Naturalist 121:364-369.

White, L. A., and S. D. Gehrt. 2009. Coyote attacks on humans in the United States and Canada. Human Dimensions of Wildlife 14:419-432.

White, M. 1973. Description of remains of deer fawns killed by coyotes. Journal of Mammalogy 54:291-293.

Whitlaw, H. A., W. B. Ballard, D. L. Sabine, S. J. Young, R. A. Jenkins, and G. J. Forbes. 1998. Survival and cause-specific mortality rates of adult white-tailed deer in New Brunswick. Journal of Wildlife Management 62:1335-1341.

Whittaker, D. G., and F. G. Lindzey. 1999. Effect of coyote predation on early fawn survival in sympatric deer species. Wildlife Society Bulletin 27:256-262.