WHITE-TAILED DEER HUNTING AND HABITAT USE IN ROBERT ALLERTON PARK

BY

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THESIS

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ABSTRACT

Using Robert Allerton Park (RAP) and the immediately surrounding properties in east-central Illinois as a study site, my objectives were to investigate changes in deer habitat use and spatial clustering following 10 years of deer removal in RAP. I evaluated changes in annual deer counts within RAP's three main habitat types, dry mesic upland forest, wet mesic floodplain forest and developed land using a generalized linear mixed model. Annual counts were categorized into two periods: no deer removal (1988-2004) and deer removal (2005-2015). Second, I used Moran's I spatial autocorrelation measures to evaluate annual changes in deer clustering. To evaluate changes in spatial clustering as a result of deer removal, I used Getis-Ord General Gi* hot spot analysis to compare spatial clustering between periods of no removal and removal. As expected, my results indicate that the number of deer removed annually decreased deer count in RAP. When analyzed by period, deer removal affected deer count, however, this impact varied between habitat types. Wet mesic floodplain forest and developed areas experienced insignificant reductions in deer count between periods whereas dry mesic upland forested habitats experienced significant reductions. Moreover, I detected an increasing trend in annual deer clustering across the study area prior to deer removal. Once the removal program was implemented, I observed a decrease in deer clustering across years. Changes were evident in both cluster location and size across the study site between periods. In conclusion, more deer were observed in wet mesic floodplain forest and developed land following removal which could be explained by the deer removal program, preferential habitat selection, temporal changes in understory quality or a combination of these factors.

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BACKGROUND ON ROBERT ALLERTON PARK

Introduction

Robert Allerton Park (RAP) is a 1,500-acre wildlife preserve, landscaped garden and public park located in east-central Illinois four miles southwest of Monticello, Illinois (Szafoni et al. 2012). The property has been owned and managed by the University of Illinois at Urbana-Champaign since 1946 after being donated as a gift by the original owner, Robert Allerton. Natural areas make up 95% of the total park and there are nearly fifteen miles of hiking trails. Approximately 50% of the park is inaccessible to the public for the purpose of maintaining and protecting its native plant and animal species (Boggess and Geis 1967). The Sangamon River runs east-west through the center of the park with two different creeks branching from it. The topography of the park decreases in elevation towards the south and includes exceptional examples of upland and old growth floodplain forests along with restored prairies and wetlands.

Vegetation

Between 1975 and 1978, the Illinois Natural Areas Inventory (INAI) was created with the purpose to survey all “high quality natural areas” throughout the state of Illinois (White 1978, 2009). It was the first attempt in United States history to create a systematic statewide inventory with the goal of identifying, preserving, and protecting a state’s natural heritage (White 1978, 2009). A natural area is defined by the INAI as:

> “A tract of land or water that 1. has a natural configuration or sufficient buffer land to insure its potential for protection and proper management and 2. meets one or more of the criteria in the following seven categories: ecological areas, endangered species habitats,

relict species habitats, geologic areas, natural study areas, unique natural areas, or aquatic areas." (White 1978)

The Illinois Natural Areas Inventory classifies Illinois' communities of plants and animals into 93 natural communities based on important natural features, and then each of the natural communities are graded based on their natural quality. For a natural feature to qualify as important, it must increase the preservation value of a natural area or act as an element of natural diversity within a community (White 1978, 2009). A few of these features are soil moisture, topographic position, and vegetation. Natural quality is a measure of the degree of disturbance within the community and helps describe a community's change in natural diversity, species composition, and structure as a result of the disturbance. Natural areas containing communities that are relatively stable or undisturbed receive a grade A while early successional or severely disturbed natural areas receive a grade E (White 1978, 2009).

During the INAI's first survey of Robert Allerton Park in 1976, the park was classified into four key community categories: dry mesic upland forest, mesic upland forest, wet mesic floodplain forest and developed land. The inventory also noted areas of tree plantations, successional fields and cropland within the park. During the update to the inventory conducted 2008-2011, it was determined that those four main community types remained within the park and all natural communities either maintained or increased their integrity and natural quality since the previous survey (INAI 1976, 2010).

Dry mesic upland forest makes up 50.8% of the park and is dominated by mature to older growth oak and hickory trees. Different mesic upland forested areas within the park vary in degree of disturbance and are given letter grades of A (old growth undisturbed or stable communities) through D (very early successional or severely disturbed communities). Dry-mesic is a soil moisture class defined as “soil that is well-drained where water is removed from the soil readily but not rapidly” (White 1978, 2009). Dry mesic upland forest communities are found near the outer boundaries of the park and away from the Sangamon River which runs through the center of the park. In order to maintain the oak-hickory forest type and control for exotic plant species, about 500 acres undergoes a prescribed burn every ten years.

Grade A dry mesic upland forested habitats are found south of the Sangamon River and maintain open ground level structure with infrequent areas consisting of exotic/invasive species such as multifloral rose (*Rosa multiflora*), garlic mustard (*Alliaria petiolata*), privet (*Ligustrum* spp.), oriental bittersweet (*Celastrus orbiculatus*) and bush honeysuckle (*Lonicera* spp.). The canopy consists of woody mesic tree species such as sugar maple (*Acer saccharum*), black cherry (*Prunus serotina*), elm (*Ulmus* spp.), hackberry (*Celtis occidentalis*), and others (Szafoni et al. 2012). The park’s grade B dry mesic areas also have open ground level structure with relatively more scattered areas comprising the same invasive plant species (Szafoni et al. 2012). Areas graded C within RAP’s dry mesic upland forest habitat maintain greater infestation of exotic and mesic species and, consequently, denser ground cover. The lowest quality dry mesic habitats, graded D regions, are mostly former cattle pasture that have been left unmanaged after grazing ceased and during repopulation of woody vegetation. The ground cover is densest in these regions and maintains the highest amounts of exotic/invasive plant species (Szafoni et al. 2012).

Wet mesic floodplain forest is composed of roughly 70% wet and 30% mesic forest types and comprises 42.1% of the park. Wet-mesic soil is “somewhat or imperfectly poorly drained” (White 1978, 2009). These communities are located in the center of the park surrounding both the north and south sides of the river. Old canopy trees, herbaceous vegetation layers and an open understory are common characteristics found throughout RAP's wet mesic floodplain forested areas. The entirety of this habitat type was scored a grade B indicating that the communities are either lightly disturbed or late successional. Robert Allerton Park's wet mesic floodplain forest habitats are dominated by oak (*Quercus* spp.) and hickory (*Carya* spp.) tree species, although black locust (*Robinia pseudoacacia*) makes up the majority of wet mesic floodplain forested areas near the north-west corner of the park (Szafoni et al. 2012).

Mesic upland forest makes up only 13.14 acres, or less than 1% of the total park's area, and consists of two narrow strips of land in the center of the park. The land was assigned a grade of A and is of high quality, undisturbed, and consists of a rich understory of herbaceous vegetation. Mesic soil is defined as moderately well drained and the soil is able to remain wet for a small but significant part of the time (White 1978, 2009). Steep slopes are characteristic of these communities within the park. As a result, erosion and young, smaller trees are common.

Developed land is a category reported within RAP's natural areas inventory, however, it is not classified as a natural area. This area comprises most of the 4-H property, the park's landing field, and a few additional areas that have previously been modified and/or have building structures on it. The 100-acre 4-H Memorial Camp is also owned by the University of Illinois and is situated on the northern border of RAP. The vegetation within the property includes some of the densest forest found on the study site along with areas of developed land.

<u>Distinguishable Characteristics</u>

Robert Allerton Park has been acknowledged as one of the state's most significant natural areas and is one of the most valuable forests in Illinois (Szafoni et al. 2012). A majority of the land was titled a National Natural Landmark in 1971 by the National Park Service and was described as containing high quality natural areas in both 1976 and 2010 by the INAI. Robert Allerton Park is one of only three areas located within central Illinois with more than 500 acres of continuous forest. Being in the heart of the Corn Belt region of the Midwest, the surrounding areas are dominated by row cropped fields which creates a unique landscape that is a rarity within the Midwest. Robert Allerton Park has been able to sustain large populations of birds, mammals, reptiles and amphibians that would have otherwise been extirpated from now agriculturally-dominated east-central Illinois. The park maintains a high diversity of plant and animal species by providing high quality resources and it is a critical stop over and breeding site for numerous migrant bird species (Szafoni et al. 2012).

WHITE-TAILED DEER POPULATION OF ROBERT ALLERTON PARK

Introduction

White-tailed deer are an important component of the natural habitat of RAP. While they can be found in abundance throughout central Illinois today, that has not always been the case. After being fundamentally extirpated from the Midwest, which included the entire state of Illinois, in the early 20th century (Wood 1910, Pietsch 1954, Sanderson and Speaker 1954, Nixon et al. 1991), white-tailed deer herds were released and relocated throughout Illinois as a recovery effort in 1903 (Pietsch 1954). Robert Allerton Park provided not only a year-round source of high quality resources for the recovering population, but it also provided a site of refuge in an area that consistently experienced substantial and, in some neighboring areas, unregulated hunting pressure during the hunting season (Nixon et al. 1991). Gladfelter (1984) found white-tailed deer population densities to be highest in areas where deer have access to croplands and where hunting pressure is minimal, making RAP an ideal location for deer population growth.

White-tailed deer throughout the Midwest are unique in the way that they have had to adapt to survive in agriculturally dominated landscapes. Midwestern deer adapted both to utilize copious amounts of food and cover provided by row crops during the summer and to thrive after complete removal of these resources in correspondence to yearly growth and harvest of farm crops. Previous studies of the RAP herd indicate that the deer exhibit unique behavior patterns compared to other modern Midwestern deer (Nixon et al. 1991, Nixon et al. 2001, Nixon et al. 2007, Nixon et al. 2008). Given the diverse, high quality habitats available to deer within and near RAP, their diet, habitat use, dispersal, migration, and home range size are distinct from other Midwestern deer.

Diet

Robert Allerton Park and the surrounding areas contain many habitats and food types that are preferred by white-tailed deer in the Midwest region. Normally, during spring and summer seasons in the Midwest, deer will consume mainly forbs and grasses while crop residues and hard mast will become a large portion of their diet in the fall and winter seasons. Crops can make up 30% of a deer's diet during the spring season when harvests are most abundant (Hewitt 2011). Outside of the Midwest, however, yields have not been documented to make up more than 15% of a deer's diet (Hewitt 2011). The percentage of crops making up white-tailed deer diet is further broken down by region and season in Table 1.1 (*Source*: Adapted from Hewitt, D. 2011. *Biology and Management of White-tailed Deer*.). In intensively farmed regions such as Piatt County, Illinois, crops offer a limitless supply of highly nutritious food to deer and, therefore, make up a majority of their diet year around. Gladfelter (1984) and Nixon et al. (1991) found that farm crops comprise up to 78% of a deer's diet in agriculturally dominated areas. During Nixon et al.'s 1991 study of RAP deer, 60% of the volume of food eaten during the winter was farm produced. Within RAP, hard mast and browse, two preferential food types for white-tailed deer, are available during the fall and winter seasons when crops and crop residues are depleted (Nixon et al. 1991).

Habitat Use

In addition to preferred food types, RAP also contains preferred deer habitats. Although white-tailed deer have adapted to use almost every ecosystem within North, Central, and most of South America (Teer 1996), this species still shows preference over the habitat types in which they predominantly reside within their home range. White-tailed deer more commonly reside in early successional forests where disturbed vegetation is greatest compared to later successional forests. Disturbed vegetation maintains a higher diversity of foliage which is favored by white-tailed deer (Teer 1996). Deer often occupy densely wooded forests where forage and cover tends to be abundant and they favor more mesic rather than xeric habitats in all regions of the U.S. (Teer 1996, Hewitt 2011). These same preferences are seen in Midwestern and, more specifically, central Illinois deer. Dense forest makes up much of the natural areas in RAP and over 750 acres consists of high quality mesic or dry-mesic habitat. Just over 400 of those acres are more disturbed, early successional forest type.

Nixon et al. (1991) observed through drive counts (i.e., counts conducted from a moving vehicle platform) that deer were more abundant in early successional forests, which provides a low tree canopy and dense understory, in winter and summer. They also observed lowest abundance in bottomland and oak-hickory forests during the winter, spring and fall. The park's bottom lands consist of old and old second growth floodplain forests, a fairly open understory, and lower than expected diversity at the ground layer. Old growth forests are first generation forests which have never undergone disturbance. Old second growth forests are second generation/regenerated forests after having undergone one disturbance event. The oak-hickory forests are also old and old second growth forests with an even more open understory. Through radio-collaring research conducted at RAP, Nixon et al. (1991) observed similar results, with collared deer favoring early successional forest and forage crops and avoiding bottomland forests during winter. Females also avoided oak-hickory upland forests during late spring presumably because of the lack of understory provided during the fawning period (Nixon et al. 1991). Similarly, yearling and older females selected diurnal resting sites more often in early successional forest and rested in oak-hickory upland and bottomland forest less than expected (Nixon et al. 1991).

Dispersal

White-tailed deer living in agriculturally dominated landscapes have adapted in many ways to live and thrive in this type of environment. The Robert Allerton Park deer herd is a prime example of this. Dispersal is a permanent movement away from a deer's natal home range to establish a new home range in another location (Kammermeyer and Marchinton 1976a, Nixon et al. 1991, Nelson 1993). While it is common for male white-tailed deer to disperse in most regions across the country, it is only in landscapes where forests are sparse and fragmented do we observe females dispersing also (Sparrowe and Springer 1970, Nixon et al. 1991, Hansen et al. 1997). Female dispersal has been especially notable in the rural Midwest where patches of forests are scattered between large expanses of row cropped fields. Table 1.2 displays the percent of males and females dispersing in various regions of the United States.

Nixon et al. (1991) found that the proportion of deer dispersing away from RAP was dictated by age, sex, and social position and both sexes typically dispersed between the months of April and July. A small proportion of males were also observed dispersing from the park between the months of September and November (Nixon et al. 1991). In studies carried out in agricultural landscapes, the amount of woody cover available significantly affected both the proportion of females dispersing (Nixon et al. 2007) and the dispersal distance (Long et al. 2005) each year. Resource competition and environmental conditions can also affect dispersal behavior (Andreassen et al. 2002). However, at RAP, female densities, mother's age, and breeding status had no significant effect on dispersal behavior in and around the park. More specifically, between 1980 and 1985, despite a steady increase in population, Nixon observed that approximately half of that year's fawns (of both sexes) and 20% of yearling females dispersed from RAP and surrounding areas in any given year (Nixon et al. 1991). Further, during the 1982-1985 study in RAP, spring deer densities had no significant impact on the number of deer dispersals that occurred that year (Nixon et al. 1991). In a later study, Nixon et al. (2008) found that, while almost half of females dispersed from east-central and northern Illinois study sites, not even a quarter of the females in a west-central Illinois region dispersed. This may be related to the amount of forested land available to deer in these regions. While forests make up less than 3% of east-central and northern Illinois regions, west-central Illinois is 20% forested (Nelson 1993, Nixon et al. 2007).

Seasonal Migration

While dispersal behavior by both sexes has been observed at RAP, only female deer migrate seasonally to summer and winter ranges (Nixon et al. 1991). Although male deer have been reported to migrate in states such as New York (Tierson et al. 1985), Michigan (Van Deelen et al. 1998) and Minnesota (Hoskinson and Mech 1976), seasonal migration is a rare occurrence in males in central and northern Illinois (Nixon et al. 2008). Migration to summer ranges outside of the park typically begins during late February and extends until early July while migration back to winter ranges takes place between September and early January. Females move away from their home ranges in the summer to forage in nutrient-rich agricultural fields outside of their home range (Nixon et al. 1991, Smith 1991). After crops have been harvested and can no longer be utilized as a food or cover source, females regather in forested areas, such as RAP, which provide these two resources throughout the winter. Annually, 17-21% of the yearling and older females migrated seasonally, moving off the park property during the spring pre-birthing season and returning in late fall or early winter after the fawn-rearing period (Nixon et al. 1991).

Seasonal migration is more prominent in regions that experience harsh winters (Nelson and Mech 1981, Marchinton and Hirth 1984, Sabine et al. 2002). However, Illinois deer migration rates are substantially lower than other states with similar winters. Nixon et al. (2008) reported female migrant rates of 21.5%, 9.4 %, and 14.6% in east-central, west-central, and northern IL study sites, respectively. Tierson et al. (1985) reported 50% of both male and female deer migrating in a heavily forested region in New York. Similarly, Van Deelen et al. (1998) documented migration rates of 40% and 67% at two different forested study areas in Michigan. The continual abundance of food and cover sources provided by agricultural fields throughout Illinois may be a reason for comparatively low seasonal migration rates by white-tailed deer (Nixon et al. 1991, Nixon et al. 2008).

Home Range

A home range is an area habitually occupied by an individual deer to search and utilize food, water, and cover resources. Social interactions and caring for young also occur within the home range (Burt 1943). Home range size varies with several factors including, but not limited to sex and age (Cederlund and Sand 1994, Nicholson et al. 1997, Relyea et al. 2000), season (Nicholson et al. 1997), and distribution and availability of resources (Schoener 1981, Ford 1983, Tufto et al. 1996). When resources are high quality, abundant, and evenly distributed in an area, deer home ranges are often smaller than in areas that are less productive. Conversely, deer inhabiting highly fragmented forested areas have larger home range sizes due to the need to travel farther to meet their food and cover requirements (Marchinton and Hirth 1984). Table 1.3 displays home range sizes by sex and season and portrays the high variability that occurs between regions and habitat types within the country.

During the winter season in northern regions, home ranges tend to be smaller as deer minimize movement in an attempt to maximize energy conservation (Moen 1976, Parker et al. 1984). However, in agriculturally intense areas, winter home range sizes have been observed to be more than double those of summer home ranges (Nixon et al. 1991, Brinkman et al. 2005). During the summer, field crops provide an abundance of cover and nutritious food. Therefore, deer do not need to regularly go out and seek these resources and can thrive when inhabiting much smaller home ranges (Brinkman et al. 2005). In Piatt County, deer home ranges were larger in winter than in summer for both males and females. Additionally, male home ranges were larger than females' during both summer and winter periods (Nixon et al. 1991). While males select home ranges based on food source availability, females choose home ranges that are optimal for fawn rearing (Nixon et al. 1991, Nixon et al. 1994).

Response to Hunting

Frid and Dill (2002) suggested that white-tailed deer and other prey species are likely to respond to human presence in a similar manner as to how they respond when encountering other predators on the landscape. This predation response will vary based on the type of risk, environment, and temporal scale associated with each encounter (Dasmann and Taber 1956, Kilgo et al. 1998, Karns et al. 2012). Earlier studies have demonstrated that deer will leave or expand their home range when subjected to hunting pressure. Sparrowe and Springer (1970) observed white-tailed deer herds breaking up and individual deer moving away from their home ranges during the hunting season in an intensively farmed and grazed region in South Dakota. Similarly, VerCauteren and Hygnstrom (1998) observed shifts in female white-tailed deer home ranges towards permanent cover during the hunting season. Studies have also observed deer response to hunting within their home range. Multiple studies have recognized deer using nonhunted refuge areas within or adjacent to their home ranges during the hunting season (Zagata and Haugen 1973, Kammermeyer and Marchinton 1976b). However, within both studies, deer did not move long distances beyond their home ranges in search of refuge areas. Kufeld et al. (1988) found that female mule deer inhabiting a mountainous-grassland region of Colorado sought out densely covered regions within their home ranges more frequently during periods of high hunting pressure. More recently, Little et al. (2015) reported that bucks reduced movements and used smaller areas in response to hunter presence on an Oklahoma study site containing bottomland and upland forested areas along with grassland.

However, other studies suggest white-tailed deer herds do not respond to local hunting. Magle et al. (2015) observed no effect on home range size due to harvest intensity in the south-central Wisconsin area which included regions of forest, cropland, and grassland. In a 50% forested, 20% row cropped and 13% fallow field study area in Maryland, Karns et al. (2012) observed only temporary flight responses by deer away from hunter disturbance and neither temporary nor permanent shifts were made in deer home ranges. Nixon et al. (1991) studied deer movement in response to hunting pressure outside of RAP during the 1980's when hunting was not allowed on RAP. Radio collared deer with home ranges that included areas both inside and outside of the park did not make movements into the park during the hunting season. Likewise, deer did not shift migration periods to avoid traveling outside of RAP during the hunting season. Furthermore, female home range size did not vary before, during, or after hunting collectively indicating that deer did not exhibit observable responses to hunting (Nixon et al. 1991).

HISTORY OF WHITE-TAILED DEER RESEARCH AT ROBERT ALLERTON PARK

<u>Introduction</u>

Robert Allerton Park biologists have been studying the resident white-tailed deer population since 1980 (Nixon et al. 1991). The park functioned as an area of refuge for the local deer herd since the University of Illinois was granted ownership of Robert Allerton Park in 1946 (Nixon et al. 1991). While archery and shotgun hunting was not regulated in many of the surrounding properties and many properties were hunted heavily each season, RAP prohibited any type of hunting on the property until 2004.

The vegetation, absence of hunting and minimal movement barriers within the park made Robert Allerton Park an ideal location to study the natural biology and behavior of Midwestern white-tailed deer. Beginning in 1980, Nixon et al. (1991) conducted an exhaustive study of white-tailed deer in Robert Allerton Park, including estimates of yearly deer population numbers, cause-specific mortality rates, annual and seasonal survival, fawn survival, migration rates, dispersal rates and distances, deer density, habitat selection and availability, forage availability and home range size. Over the years, research teams used several techniques to gather data including drive counts, aerial surveys, and radio telemetry.

<u>Piatt County Survey Area</u>

In 1981, the park biologists began conducting annual aerial counts during the winter season to locate and count deer within and around the park. Visual aerial surveys were conducted over the Piatt County Survey Area once a year thereafter to detect trends in deer population numbers and densities throughout the survey area. The Piatt County Survey Area (PCSA) is a 7,300-acre area that includes the entirety of Robert Allerton Park, the 4-H property within RAP, the university-owned farms bordering RAP (2,800 acres), an 800 acre Illinois Department of

Natural Resources property, and 2,000 acres of multiple private properties surrounding the park (Figure 2.1).

Aerial surveys are favored over other types of survey techniques because they are the fastest and most efficient way of gathering abundance and distribution information on remote or widespread wildlife populations (Caughley and Grigg 1981). However, correctly carrying out aerial surveys is important to the quality of data. Biased population estimates may arise as a result of too high of aircraft speed or altitude, poor snow conditions, or observer bias (Caughley 1974). It has been noted that double-count techniques which involves two people independently counting animals from the same side of the aircraft and line-transect techniques allow for the greatest precision and accuracy when conducting aerial counts (Magnusson et al. 1978, Choquenot 1995). Furthermore, flights are expensive and flight vehicles can be difficult to secure.

In RAP, careful attention was paid to the aerial count methods. Although annual aerial surveys were the goal, the RAP biologists were not able to conduct aerial surveys for six of thirty-five years following 1981 because of limited helicopter availability, limited funds or lack of snowfall. While aerial survey techniques and accuracy cannot be confirmed prior to the early 2000's, biologists regularly recorded the weather conditions and flight path after each survey to provide a consistent baseline between survey years. Additionally, Nixon et al. (1991) noted that the 1981-1985 aerial counts were conducted when there was at least 10 cm of fresh snow cover. The data were considered reasonably accurate given the long flight times for each count, the flat terrain throughout the study site, and close agreement between aerial counts and known radio-marked deer locations. Furthermore, the biologists would drive deer out from densely forested areas just prior to each aerial count. The flights were performed after mid-January, after most marked migrating females completed their winter migration and returned to the study site (September-early January; Nixon et al. 1991).

In addition to visual counts, forward looking infrared surveys were conducted from 2007 - 2009 to evaluate the effectiveness of infrared thermal imagery as an alternative tool for performing aerial counts **(**Becker unpublished). Because thermal imaging does not require snow on the ground, it allows aerial surveys to be conducted during more variable weather conditions (Haroldson et al. 2003). Forward-looking infrared cameras work best at night when the thermal difference between deer and the environment is greatest. Potvin and Breton (2005) found that infrared imagery is ineffective for areas of closed forest canopy (Croon et al. 1968, Haroldson et al. 2003), which severely limits the usefulness of the tool in Robert Allerton Park. Most studies applied thermal imaging to captive populations of a known size and application of the tool to wildlife surveys was relatively untested and its capabilities were unclear (Croon et al. 1968, Wiggers and Beckerman 1993). However, Haroldson et al. (2003) found precision and accuracy of thermal imaging to be poor when applied to wildlife. Conversely, Becker (unpublished) found no significant difference between visual and infrared counts conducted on the PCSA and both were, therefore, included in data analysis for this study.

During the first twenty years of continuous surveillance, the RAP biologists observed a drastic increase in deer numbers on the Piatt County Survey Area. The 1981 survey recorded fewer than one hundred deer throughout the PCSA. By 2004, the population expanded to more than 700 deer in that same region (Szafoni et al., 2013). As deer populations become overabundant, over-browsing by deer hinders forest regeneration, which subsequently modifies the structure and composition of the forest communities (Harlow and Downing 1970, McCullough 1979, Côté et al. 2004). At RAP, the understory was decimated in many areas of the park during the period of increasing deer population. Horsley et al. (2003) found a negative trend between hardwood species tree abundance and richness and increasing deer density. Given the large number of deer and the observed damage to the park's flora, the RAP deer biologists implemented a deer management program in 2004 to reduce deer density and support the regeneration of the vegetation within the park.

Robert Allerton Park Deer Management Program

Robert Allerton Park initiated a deer management program through hunting for the first time in the fall of 2004 through the winter of 2005. The goal of the program was to protect and maintain the high quality of the land by reducing the white-tailed deer population and, thus, allow for regeneration of native flora which are palatable plant species to deer (Szafoni et al. 2012). Regrowth of native plant species would then aid to minimize unpalatable exotic species growth. The "earn-a-buck" reduction technique was applied, where hunters were first required to harvest an antlerless deer in order to be able to harvest an antlered male that season. "Earn-a-buck" regulation has the capacity to successfully increase doe and fawn harvests and decrease herd size (Boulanger et al. 2012). Additionally, trained professionals culled deer at the end of the hunting season for the first three fiscal years (2005, 2006, 2007) to meet the annual intended harvest quota because culling programs reduce deer densities and densities do not rebound for multiple years after the culling period (Table 2.1; DeNicola and Williams 2008).

The deer management program met their goal of protecting and maintaining the park's high quality land within RAP's first four hunting seasons (fiscal years 2005 through 2008). Winter deer counts decreased from over 700 deer to fewer than 300 within two hunting seasons. Additionally, in 2009, Becker (unpublished) observed signs of recovery in prairie trillium, snow trillium, and Virginia bluebells wildflower species within the park. Less than 200 deer have been observed on the PCSA in the last three winter aerial counts (two counts in fiscal year 2013 and one count in 2015), indicating a smaller, more stable deer herd than previous years (Table 2.1).

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TABLES

Table 1.1. Average (Minimum, Maximum) Seasonal Percent Composition of White-tailed Deer Diets Derived from Crops, based on Published Studies in Midwestern, Northeastern, Northwestern, Southeastern, and Southwestern North America (*Source*: Adapted from Hewitt, D. 2011. *Biology and Management of White-tailed Deer*).

	Diet based on crops			
Region	**Spring**	**Summer**	**Autumn**	**Winter**
Piatt County, IL	84	48	46.7	60
Midwest	30 (0,84)	8 (0,48)	15 (0,47)	13 (0,60)
Northeast	0 (0,0)	2 (0,10)	1 (0,3)	0 (0,0)
Northwest	11 (0,46)	13 (0,43)	9 (0,47)	6 (0,39)
Southeast	0 (0,0)	4 (0,39)	3(0,23)	4 (0,25)
Southwest	0 (0,7)	0 (0,3)	1 (0,20)	2 (0,36)

State/Provinces in each region: Midwest = IL, IN, MI, MN, MO, OH; Northeast = ME, NH, PA, New Brunswick, Ontario, Quebec; Northwest = CO, ID, MT, ND, SD; Southeast = AR, FL, GA, LA, MA, NC, TN, VA, WV; Southwest = AZ, OK, TX, and northeast Mexico.

Table 1.2. Percent of white-tailed deer that disperse in the United States stratified by age, sex, and region.

	Males			**Females**			
Location	**N deer**	**Age**	**Percent Dispersing**	**N deer**	**Age**	**Percent Dispersing**	**Study**
New York	79	1-1.5 years	41	240		4	Tierson et al. (1985)
Georgia	10	1.5-2.5 years	50	21		5	Kammermeyer and Marchinton (1976a)
Montana	50	≤ 18 months	46	53	≤ 18 months	17	Dusek et al. (1989)
Minnesota	10	≤ 17 months	70	6	≤ 3 years	0	Nelson and Mech (1984)
Northeastern Minnesota	28	1-1.5 years	64	7	1-1.5 years	20	Nelson (1993)
Southern Wisconsin	58		29	48	≤ 12 months	2	Magle et al. (2015)
Northern Illinois	17	≤ 12 months	68	13	≤ 12 months	45	Nixon et al. (2007)
West-central Illinois	28	≤ 12 months	78	7	≤ 12 months	22	Nixon et al. (2007)
East-central Illinois	33	≤ 12 months	57	20	≤ 12 months	49	Nixon et al. (2007)

Table 1.3. Home-range size in hectares (ha) for white-tailed deer in the United States stratified by region, habitat type, season and sex.

Location	Habitat Type	Season	Sex	N Deer	Home Range (ha)	References
New York	Forested	Summer	F	64	221 ± 19 SE	Tierson et al. (1985)
		Winter	F	45	132 ± 18.3 SE	
		Summer	M	34	233 ± 23.4 SE	
		Winter	M	12	150 ± 31.6 SE	
Minnesota	Forested	Summer	F	5	83	Nelson and Mech (1981)
		Fall	F	5	225	
		Summer	M	5	319	
		Fall	M	5	749	
Minnesota	57% residential, 15% conservation reserves	Summer	F	19	50.4 ± 6.8 SD	Grund et al. (2002)
		Winter	F	30	85.3 ± 5.8 SD	
Michigan	Primarily recreation and commercial timber	Summer	F	37-49	1255 - 3037	Van Deelen et al. (1998)
		Winter	F	42-51	730 - 1859	
Quebec	20% Agricultural Fields, 80% forested	Summer	F	13-24	910-2812	Lesage et al. (2000)
		Winter	F	13-Jul	102-112	
		Summer	M	14-May	1144-1247	
		Winter	M	7-Apr	193-272	
South Dakota	Cultivated land and pasture-grassland	Summer	M/F	49	920 ± 100 SE	Grovenburg et al. (2009)
		Winter	M/F	27	1020 ± 120 SE	
South Dakota	Intensely farmed, grazed land	Summer	M/F	8	259.2 ± 129.5 SE	Sparrowe and Springer (1970)
		Winter	M/F	10	699.8 ± 440.3 SE	

Table 1.3 continued. Home-range size in hectares (ha) for white-tailed deer in the United States stratified by region, habitat type, season and sex.

Location	Habitat Type	Season	Sex	N Deer	Home Range (ha)	References
Southern Wisconsin	Forested, Agriculture	Gestation (Jan-May)	F	176	114 ± 18 SE	Magle et al. (2015)
		Parturition (May-July)	F	123	88 ± 20 SE	
		Prerut (July-Oct)	F	130	96 ± 25 SE	
		Rut (Oct-Jan)	F	69	62 ± 5 SE	
		Gestation (Jan-May)	M	29	166 ± 17 SE	
		Parturition (May-July)	M	13	153 ± 37 SE	
		Prerut (July-Oct)	M	50	109 ± 14 SE	
		Rut (Oct-Jan)	M	34	184 ± 31 SE	
Illinois	Residential and undeveloped land	Spring	F	26	53.0 ± 5.2 SE	Storm et al. (2007)
		Winter	F	34	90.6 ± 9.7 SE	
Piatt County Survey Area, IL	64% row cropped, 36% forested	Parturition (May-July)	F	29	55 ± 7 SE	Nixon et al. (1991)
		Postbreeding (Dec-May)	F	44	177 ± 14 SE	
		Prebreeding (July-Oct)	F	36	110 ± 13 SE	
		Rut (Sept-Jan)	M	3	480 ± 113 SE	
		Prerut (May-Aug)	M	8	323 ± 49 SE	
		Postrut (Jan-April)	M	9	440 ± 19 SE	

CHAPTER 2: WHITE-TAILED DEER HUNTING AND HABITAT USE IN ROBERT ALLERTON PARK

INTRODUCTION

Managers often implement controlled deer removal programs to manage white-tailed deer (*Odocoileus virginianus*) populations within a region (Hansen and Beringer 1997, Kilpatrick and Walter 1999, McDonald et al. 2007). Areas maintaining high deer densities frequently experience negative effects on vegetation (Tilghman 1989, Harlow and Downing 1970, Strole and Anderson 1992) and may experience increased rates of infectious disease where diseases are prevalent (Bosler et al. 1983, O'Brien et al. 2002, Habib et al. 2011). As a supplement to hunting programs, or in areas where public hunting is not allowed or where public safety is a concern, localized culling is can be used to reduce and maintain lower deer densities (Ver Steeg et al. 1995, DeNicola and Williams 2008).

While both public hunting programs and culling have the potential to effectively reduce deer numbers, it is unclear how these deer removal methods affect habitat use and spatial clustering amongst deer during and after the removal period. Prior studies of deer response to removal activity range broadly from no response to marked response. Although evidence for permanent home range relocation resulting from deer removal is scarce (Sparrowe and Springer 1970, Tosa et al. 2017), multiple studies report that deer shift their home ranges towards areas with more permanent cover in response to deer removal activity (Kufeld et al. 1988, VerCauteren and Hygnstrom 1998, Kilpatrick and Lima 1999). Similarly, studies have observed deer temporarily utilizing areas protected from deer removal after experiencing removal pressure (Kammermeyer and Marchinton 1976, Kilpatrick and Lima 1999, Rhoads et al. 2013). Karns et al. (2012) observed no shifts in deer home ranges as a result of deer removal activity. However, this study did observe deer temporarily fleeing their home ranges and shifting space use within home ranges in response to deer removal activity. Conversely, Nixon et al. (1991) and Magle et al. (2015) observed no response by deer to local hunting activity.

Furthermore, studies have reported changes in social grouping and spatial clustering of deer as a result of deer removal programs (Williams et al. 2008, Schauber et al. 2007, Tosa et al. 2017). Tosa et al. (2017) observed shifts in home range by remaining juvenile deer as they sought direct contact with other remaining deer after removal of their social group. Williams et al. (2008) observed unrelated female deer increasing direct contact amongst each other after removing the rest of their social group. Thus, the effects of deer removal on both deer habitat use and spatial clustering varies within the literature.

Given the wide variety of potential responses of deer to removal activity, it is difficult to predict a response in any specific area, especially those with high quality deer habitat. Positioned in the middle of the United States' Corn Belt region, Robert Allerton Park (RAP) is one of only three areas in central Illinois with greater than 500 acres of continuous forested landscape (Figure 2.1). RAP is a 1,500-acre public park, landscaped garden and wildlife reserve situated in east-central Illinois just south-west of Monticello, Illinois (Figure 2.1). The park is a national natural landmark owned by the University of Illinois and consists of high quality forests, prairies and wetlands (Szafoni et al. 2012). More than 95% of RAP is considered natural areas and the park's forested areas consist of dry mesic upland forests (54%), mesic upland forests (1%), and wet floodplain forests (45%).

Deer count and density data within and around RAP were collected beginning in the 1980s. Within the first years of data collection, an increasing trend in deer numbers was evident (Nixon et al. 1991; Table 2.1). Prior to the fall of 2004, hunting was not allowed within RAP although surrounding properties experienced relatively constant levels of hunting each year. Deer numbers continued to increase until the fall of 2004, when RAP initiated a deer management program (hunting and culling) with the primary goal of protecting the park's native flora by reducing deer density in RAP. The deer population declined considerably as a result (Table 2.1).

Understanding that there are multiple possible outcomes regarding changes in deer habitat use as a result of deer removal programs, it is unknown how RAP's management program affected deer landscape use. In order to address this gap in knowledge, I have identified two specific goals for this study:

1. To evaluate changes in deer habitat use in wet mesic floodplain forest, dry mesic upland forest, and developed areas within RAP in the presence and absence of deer removal. I expect to observe an increased use of wet mesic floodplain forest and developed areas as these habitats contain the densest forest cover and previous studies have observed deer seeking dense cover during deer removal periods.
2. To assess spatial clustering of deer prior to and concurrent with deer removal in RAP. I anticipate an increase in spatial clustering as deer are exposed to deer removal.

MATERIALS AND METHODS

Study Area

The study site included 7,300 acres in east-central Illinois referred to as the Piatt County Survey Area (PCSA). Data collected from this area was used to address objective two (Figure 2.1; labeled as Aerial survey area/PCSA). The PCSA consists of the 1,500-acre RAP, a 250-acre 4-H Memorial camp, the neighboring 2,800-acre University of Illinois-owned farm properties, the Illinois Department of Natural Resources' 800-acre property, and 2,000 acres of surrounding private properties (Figure 2.1). Piatt County has a temperate continental climate (Trewartha 1986) with average temperatures typically ranging from 24.8^{o} F (January) to 74.9^{o} F (July) (Illinois State Water Survey Records for Urbana, IL). Average annual precipitation for Piatt

County is 40.77 inches (Illinois State Water Survey Records for Cisco, IL) and the region receives an average of 23.2 inches of snowfall annually (Illinois State Water Survey Records for Urbana, IL). Row crops including corn, soybean and small areas of wheat along with improved pasture make up 64% of the survey area while the remaining 36% is forested. Crops are planted between April and early June; soybeans and corn are harvested in the middle of September and late October, respectively. A majority of the forested areas within the study site are found in RAP and the Illinois Department of Natural Resources property.

Illinois Natural Areas Inventory/Vegetation Information

Vegetation data within RAP and the bordering 4-H Memorial Camp was obtained from the 2010 update to the Illinois Natural Areas Inventory (INAI)'s original inventory of Illinois' high quality natural areas conducted in 1976 (White 1978, 2009). The original inventory divided the region's natural areas into four different habitat types: wet mesic floodplain forest, dry mesic upland forest, mesic upland forest, and developed land (Figure 2.2). While developed land is a category within the INAI, it is not classified as a natural area itself. The developed land in RAP and the 4-H property consists of a campground site, multiple building structures, an aircraft landing field, and highly modified forested areas. Each habitat type within RAP was assigned a quality grade (A through D) based on habitat quality and degree of disturbance (Figure 2.2). The densest forest cover inventoried by the INAI was located in wet mesic floodplain forest and developed area habitats. These areas make up 42.1% of RAP and the majority of the 4-H camp. A second survey conducted in 2010 reported that each of the natural habitats within RAP had preserved or improved its integrity and natural quality (INAI 1978, 2010). However, changes in understory quality across years were not quantitatively documented and, therefore, were not accounted for in this analysis. All areas graded by the INAI were used to develop the statistical model in objective one (Figure 2.2, shaded areas).

Deer Survey Data

For the current study, I used annual deer numbers and locations from aerial count survey maps that were generated during winter surveys from fiscal years 1988 to 2015. Data for the number of deer and location on the study site was extracted from annual aerial counts by scanning each aerial map generated by the surveys, georeferencing the image, and digitizing individual deer locations using ArcMap 10.3 (ESRI, Redlands, CA). I generated a hexagon grid layout of the PCSA using the Create Hexagons tool in ArcGIS. I specified division of the survey area into identically-sized hexagons (width = 328 feet). For each hexagon, I assigned a numeric value based on the number of deer found within that area during each survey. I selected a hexagon width small enough to capture deer location detail between flown transects given the aerial surveys' transect width of 400-500 feet. I assigned each hexagon to one of two areas: 1) the area inside RAP and 2) the area outside of the park but within the study area and the aerial survey boundaries. I also assigned within-park hexagons to their respective INAI habitat type and grade.

Visual aerial counts were conducted by the RAP deer biologists each year between the months of December and April. Two bridges along the Sangamon River served as boundaries of the Piatt County Survey Area and the aerial counts began at the northeast boundary (Bridge Street Bridge) and concluded at the southwest boundary (Hogchute Bridge; Figure 2.1). Ideal visual aerial counts were conducted during daytime when fresh snow cover exceeded 3 inches. A helicopter followed the same annual flight pattern consisting of equally spaced north-south transects set 400-500 feet apart. The flight was conducted at a height of 230 feet and a speed of

40 knots. A double count method (Potvin et al. 2004) was performed in which two people counted individually out of one side of the helicopter, while a third person confirmed the count on the opposite side of the aircraft. The two counters conducted the survey on the left side of the helicopter, while the individual making the confirmation viewed the landscape from the right side of the aircraft. Each transect was flown twice so that all counts were conducted from the left side of the aircraft. Both counters recorded each deer sighting on an aerial photomap of the PCSA.

Ten additional surveys were conducted during the 2008, 2009 and 2013 fiscal years using a Forward Looking Infrared (FLIR) 8500FW camera. Like the visual surveys, FLIR surveys utilized a helicopter and flew the same flight pattern. However, the helicopter was flown at a height of 800 feet when conducting forward looking infrared surveys and transects were spaced 700-900 feet apart. These surveys were conducted at night to maximize thermal differences between deer and the surrounding environment. Flights were documented with the camera and recorded onto a DVD in order to count the observed deer on film after the flight had ended. One individual was the camera operator while one to two other people were observers, directing the camera operator towards locations with deer.

If multiple counts were taken during one fiscal year, I averaged the counts for that year for analysis. If there were multiple counts for a single fiscal year, counts conducted after early March were removed from the analysis due to its proximity to the start of deer migration and dispersal (Nixon et al. 1991, Nixon et al. 1994, Nixon et al. 2008). Counts conducted under less than ideal conditions (e.g., inappropriate weather conditions or poor camera function) were also removed from analysis (Table 2.1).

Deer Harvest Data

To measure the number of deer removed through harvests, I used RAP's deer management program data. Harvests were defined as the total number of deer removed within the November through January hunting season regardless of hunting method. The number of deer harvests was recorded beginning with the implementation of the hunting program in the fall of 2004 (Table 2.1).

The park biologists portioned the park into zones in order to control hunter density. Eight zones were created based on land features, trail and road location. Zones varied in size from 68 to 276 acres, however, each zone was allowed no more than one archery hunter per twenty acres and one shotgun hunter per thirty acres (Figure 2.3). Sign in was required prior to hunting for both morning and afternoon periods and each hunter recorded which zone they would be hunting in. Lotteries took place any time the number of hunters wanting to hunt in a specific zone was greater than that zone's allowed limit. An annual harvest quota was established based on the deer density reduction needed to protect the native flora, the number of hunters participating, and the amount of resources available that particular year.

Both shotgun and archery hunters were required to adhere to all state hunting laws. Additionally, hunters were required to harvest an antlerless deer before they were allowed to harvest a buck, referred to as an "earn a buck" deer reduction technique. All harvested deer were mandatorily checked and field dressed at a park check station where park biologists collected samples from each deer for research, disease surveillance and aging.

Archery hunting was allowed each year beginning in the 2005 fiscal year. Shotgun hunting was allowed for the 2006-2009 fiscal years and was only allowed during the first weekend of the Illinois shotgun season, which occurs in late November. Shotgun hunters were only permitted to harvest females except during the 2006 fiscal year, when the “earn-a-buck” technique was allowed.

In order to reduce deer damage to local plant communities, the deer management program aimed to remove as many deer as financial resources and hunter participation allowed in the first hunting season (fiscal year 2005). The following year, fiscal year 2006, management set a harvest quota of 300 deer to be removed within the park. After substantially reducing deer numbers within the first three years of the hunting program (fiscal years 2005, 2006, 2007), annual harvest goals were generated as opposed to strict harvest quotas (Table 2.1).

Robert Allerton Park deer biologists hired a private contractor to cull additional deer within the park in fiscal years 2005, 2006 and 2007. Culling occurred between late January and mid-February. The culling process involved baiting areas along roadsides, culling a pre-specified number of antlerless deer to meet the specified quota for the year, and removal of the bait after the culling ended. Culled deer were processed, tested for chronic wasting disease (CWD) and donated to local food pantries.

Robert Allerton Park biologists recorded the harvest permit number, date, location (zone), sex, estimated age, weight, test results for CWD and Lyme disease, removal method (archery, shotgun, or cull), and hunter name for each deer. Deer harvests from university farms and the Illinois Department of Natural Resources property bordering the park were also recorded. Most years, the number of deer harvested on the bordering private properties was obtained through communication between landowners and the park biologists, but the data on individual deer were not collected for those privately-owned areas.

Statistical Analysis

To address my objectives and evaluate the influence of deer removal efforts on habitat use and spatial clustering of deer, I divided the data into two time periods: 1) years prior to the initiation of deer removal in RAP (1988-2004) and 2) years following implementation of deer removal (2005-2015) (Table 2.1).

I incorporated all fiscal years into analysis beginning with 1988 when the first aerial count map was generated. The habitat type variable included the park's mesic upland forest, wet mesic floodplain forest, dry mesic upland forest, and developed land per classification by the Illinois Natural Areas Inventory. I further divided dry mesic habitat into categories based on its grade (A, B, C, and D), creating a total of seven different habitat types used for analysis.

Because harvests were recorded by hunting zone and not by habitat type, I estimated the number of deer removed by habitat based on zone removal records. Zones consisted of at least two different habitat types and deer harvests were assigned to each habitat based on the number of acres within each. To estimate the number of deer removed from each habitat type, I multiplied the number of harvested deer by the number of acres in the respective habitat, divided by the number of acres in the respective zone. Additionally, I estimated the number of deer removed by habitat quality (grade A-D) within the dry mesic habitat type and treated each grade as its own habitat type for analysis. To improve accuracy when generating these estimations, I removed from the analysis areas where hunters did not hunt and therefore areas where animals were not removed. These areas included either steep slopes or locations far from the nearest road, making it hard to recover harvested deer. For the first three hunting seasons, locations of culled deer were estimated by equally distributing the total number of killed deer between the habitats along the 3.5-mile road driven during the culling program.

In order to address my first objective and evaluate the influence of deer removal on habitat use, I used SAS® 9.3 (SAS Institute, Inc., Cary, NC) to generate a generalized linear regression model (SAS GLIMMIX procedure) in the assessment of the effects of habitat type and quality and the number of harvests on deer count within the park. Habitat type and grade, fiscal year, and the number of deer harvests were fixed explanatory variables. The park's seven different habitat types were split within each of the eight hunting zones to create a split-plot design, producing a total of 25 habitat-zone combinations. Deer count per year within these 25 habitat-zone areas was the response variable and the experimental unit for this model. A model comparison technique (method= LAPLACE) looking at -2 log likelihood values was used to determine the best fit model for this dataset. Alpha was set at 0.05.

Using a GLIMMIX framework allows for analysis of count data as a response variable which ranges from 0 to infinity, is not normally distributed and typically follows a negative binomial distribution. The intercept was randomized (RANDOM statement in SAS) on the subject of both fiscal year and the interaction of habitat and zone. An autoregressive randomization type was specified when randomizing on fiscal year to indicate a repeated effect across years (Random intercept / subject=fiscal_year type=AR(1)). This specification treats counts which are conducted closer together in time as more similar than counts surveyed further apart in time. Furthermore, randomizing the intercept on the interaction of habitat type and zone removes any variance caused by differences in size of the zone-habitat areas. The proc means procedure was used to generate mean deer count within each habitat type for years prior to and concurrent with deer removal in the park. Because habitat types varied in size, I divided each count by its respective habitat acres in order to get deer density for each habitat type which was then used to compare changes in mean deer count.

To further assess changes in habitat use due to deer removal in RAP, I included an additional temporal parameter (‘period’) to indicate the first period of deer counts which experienced no deer removal (1988-2004 = “0”) and the second set of counts which did experience removal (2005-2015 = “1”). As a discrete variable, I computed a least-squares means (LSMEANS) statement of fixed effects and I specified pairwise comparison between period-habitat type interactions. A studentized maximum modulus adjustment was specified (ADJUST=SMM) which is a more conservative method that protects overall error rate more effectively. Parameter estimates of deer count were produced within each of the habitat types and were compared between the two periods.

For my second objective, to assess changes in deer clustering within the PCSA due to deer removal, I used two techniques within ArcGIS’s spatial statistical toolset for exploratory spatial analysis of clustering between periods with and without deer removal. The Global Moran’s I tool measures spatial autocorrelation and provides a single index value which indicates whether the spatial pattern of features is clustered, random or dispersed within a given area. A positive index value indicates tendency towards high valued clusters, or hexagons containing one or more deer, being situated around other high valued clusters and/or low valued clusters (hexagons containing zero deer) being near other clusters with low values. Negative index values demonstrate that clusters of high value tend to be positioned around low valued clusters and vice versa, indicating dispersion among features. In addition, this tool generates a p-value for the Moran’s I index which indicates statistical significance of the data by determining whether the spatial pattern is different from one that is randomly distributed.

Using deer locations from each chronicled count and separating the PCSA into inside and outside of the park regions, two annual Moran’s I indices were obtained to detect separate trends in spatial clustering within the two areas over time. In order to evaluate any influence of RAP's management program on spatial clustering, trends in annual indices both inside and outside of the park were examined corresponding to this study's two periods of interest, survey years prior to the initiation of the removal program and years after implementation of the program. Due to inconsistencies when recording deer locations during aerial surveys in earlier years, annual deer counts between 1988 and 1994 and the count conducted in 2000 were removed from analysis.

Hot Spot Analysis, also known as Getis-Ord General Gi*, was the second spatial analysis method conducted to further explore clustering of deer within the PCSA. A Gi* statistic identifies clusters of features which contain values that are greater than what is expected due to random chance. While the Moran's I Spatial Autocorrelation tool is a global measure that produces one statistic for the entire set of features being evaluated, the Getis-Ord Gi* tool is a local indicator for spatial clustering and produces a z-score for each geographic unit across the landscape. Each z-score indicates the intensity of clustering within the specified area based on where it falls on the corresponding confidence interval. Large positive or negative scores specify clustering of areas with high or low values, respectively. A map is then produced corresponding to each of the hexagons' z-scores, allowing for visual representation of clustering across a study site. To visualize differences in deer clustering due to the deer management program, two hot spot analysis clustering maps were created corresponding to years pre- and post-removal program implementation.

RESULTS

Deer count was significantly influenced by habitat type ($F_{6,20}=2.69$, $\boldsymbol{P} = 0.0441$) and harvests ($F_{1,545}=16.38$, $\boldsymbol{P} < 0.0001$). The best fit model also included the interaction between habitat type and harvests ($F_{5,545}=5.33$, $\boldsymbol{P} < 0.0001$; Table 2.2). Based on preliminary results, I determined that the mesic upland forest habitat was too small of an area to analyze and removed the category from analysis.

Mean deer counts within each habitat type for periods before and concurrent with deer removal in RAP are summarized in Table 2.3 and Figure 2.4. Mean deer count decreased by at least a third in every habitat type, with the greatest decrease occurring in grade B dry mesic habitat (93.7%) and the smallest decrease in wet mesic floodplain forest (39.7%; Table 2.3). The reported means are raw values which have not been adjusted to control for differences in acreage between habitat types. Table 2.3 and Figure 2.5 illustrates mean deer count after being weighted by each habitat's size, resulting in mean number of deer per acre. Results in Table 2.3 and Figure 2.5 for mean deer count per acre were multiplied by 100 for easier assessment of deer count values.

Differences in least-squares means estimates of the interaction term indicate that mean deer counts were significantly different in each of the dry mesic upland forested habitats (grade A through D) between no deer removal and removal periods (Table 2.4). Mean counts were not significantly different between the two periods in the wet mesic floodplain forest habitat or the park's developed land.

Parameter estimates for the interaction term during the period corresponding with no deer removal ranged from 0.866–2.944 among the six habitats (Table 2.5). Estimates corresponding to counts within the removal period ranged from -1.908 to -2.072, with the habitats which did not experience significant differences in mean deer count (wet mesic floodplain forest and developed land) along with grade D dry mesic habitat retaining a positive association with deer count (Table 2.5).

The Global Moran's I spatial autocorrelation tool produced positive z-scores for all years both inside and outside of the park (Table 2.6). All generated p-values were less than 0.05, indicating that the clustering pattern was significant each year. Furthermore, there was an increasing trend in Moran's I indices across years both inside and outside of RAP prior to hunting in the park. After the deer management program commenced in fall 2004, decreasing trends in indices were observed in both areas. Annual Moran's I indices are presented in Figure 2.6. Since the reported trends were consistent with trends in total deer numbers both within and outside of the park during this same timeframe (Figure 2.7), I produced two linear regressions to evaluate the relationship between annual deer count and Moran's I statistic in both regions of the study site. The correlation coefficient between deer count and Moran's I value inside and outside of the park were 0.331 and 0.156, respectively (Figure 2.8).

The Getis-Ord General Gi* hot spot analysis clustering map corresponding to deer counts conducted prior to (1994-2004) and concurrent (2005-2015) with deer removal in RAP is visualized in Figure 2.9 and suggests that significant deer clustering shifted from regions primarily within RAP to areas outside of the park. In addition, sizes of deer clusters have decreased across the study site between no removal and removal periods.

DISCUSSION

This study provides a unique opportunity to evaluate changes in deer habitat use potentially attributable to deer removal over multiple decades and across a relatively stable landscape. Having several years of deer location data prior to the initiation of RAP's hunting program creates a baseline by which I can estimate changes in habitat use due to hunting activity. It is important to note, however, that while changes in RAP's habitat types and grades have not changed over the past 25+ years of data collection, there have been changes in RAP's understory throughout this timeframe in response to fluctuation in deer density which were not accounted for in this analysis.

Similar to previously cited studies (Kammermeyer and Marchinton 1976, VerCauteren and Hygnstrom 1998, Kilpatrick and Lima 1999), my results suggest that deer removal significantly alters the way deer use the landscape. The first objective of this study was to evaluate how RAP's deer management program has affected habitat use among resident deer. In addition to my statistical results indicating that harvests significantly and negatively influence deer count within the park, the mean number of deer located within each of the habitats decreased at varying proportions between no hunting and hunting periods. Mean deer count decreased least between the two periods in the park's wet mesic floodplain forests. This habitat provides dense forest cover for deer relative to other inventoried areas (Robert Allerton Park records, unpublished data) and supports my hypothesis that deer will seek out dense cover in response to deer removal. Mean deer count decreased the second least amount in developed areas. This developed region consists primarily of the 4-H property which experiences less deer removal relative to other inventoried areas and provides dense forest cover (Robert Allerton Park records, unpublished data). Moreover, average deer count decreased most in grade A and B mesic upland forests. These later-successional forested areas provide the least amount of forest cover in comparison to the other four habitat types analyzed in this study. Once deer removal began, we saw a decrease in all habitats, however, the greatest decreases were observed in least preferred habitats for deer. In addition to deer removal, a possible explanation for this could be that after deer are removed from sought-after habitats, the remaining deer move into these now unoccupied areas. Also, temporal changes in understory quality may contribute to these results.

A lack of significance in change in mean deer count between the no-removal and removal periods within wet mesic floodplain forest and developed land habitats agrees with our previous findings which indicated that mean deer count decreased least in these two habitats in comparison to the other habitats evaluated in the park. Because aerial survey techniques, time and weather conditions of surveys, deer removal outside of the park, and habitat type within RAP remained reasonably constant between these two periods, the absence and presence of deer removal within the park appears to contribute to observed differences.

In addition to alterations in deer count within each of the habitat types, spatial clustering of deer also changed in response to deer removal. Annual Moran's I statistics indicated an increase in deer clustering both inside and outside of the park prior to the initiation of the deer management program. This may be a result of greater deer density as deer counts increased seven-fold across the PCSA at that time. After the removal program was implemented, Moran's I values decreased in both areas, with a greater decline in within-park clustering where deer experienced relatively more hunting pressure. Similarly, total deer numbers also began decreasing during this same period as a direct result of deer removal, so it could be expected that a decline in deer density may also be the reason for decreased spatial clustering across the landscape. However, the small correlation coefficients obtained from the linear regressions of deer count and Moran's I indices suggest that at least one other factor besides the total number of deer must be responsible for clustering of deer across the PCSA. Additional influences that could affect deer clustering may include resource availability or changes in social cohesion due to deer removal. Mackie et al. (1998) reported larger groups of mule deer in Montana as a result of limited winter habitat availability. Multiple studies have also observed greater shared space between deer in agricultural (Kjær et al. 2007, Skuldt et al. 2008, Silbernagel et al. 2011) and fragmented (Silbernagel et al. 2011) areas where food is concentrated. Another factor that can affect deer clustering is the ability of hunting to disrupt social cohesion within wildlife populations (Tuyttens et al. 2000) which can, in turn, affect spatial clustering. Williams et al. (2008) reported interactions among unrelated female deer after matrilineal social groups were broken up due to hunting. Schauber et al. (2007) suggest that lethal population control has the ability to both decrease and increase contact rates between deer due to the effect of hunting on social cohesion. Tosa et al. (2017) reported shifted space use and increased direct contact between remaining juveniles after removing all other members of their social groups. While a reduction in group size understandably decreases the amount of direct contact between deer within social groups, it may also increase contact rates between groups as social cohesion is disrupted across the landscape. As a result, social regrouping may occur due to the species' social nature (Kilgo et al. 1998, Williams et al. 2008, Tosa et al. 2017).

My assessment of the Getis-Ord General Gi* Hot Spot Analysis maps visualizing deer clustering before and concurrent with hunting indicates that not only has clustering decreased across the study site, the size of deer clusters also decreased once hunting initiated in RAP. Possible explanations for these findings could be that hunting causes a disruption to social groups and, consequently, disorders social cohesion between deer (Tuyttens et al. 2000, Williams et al. 2008) or that hunting may decrease deer's home-range fidelity (Kammermeyer and Marchinton 1976, VerCauteren and Hygnstrom 1998, Kilpatrick and Lima 1999). Furthermore, while these results support the idea that resident deer tend to shift their distribution and seek out the same areas within the park during the hunting season, it does not necessarily mean that deer are affiliating with one another or creating social groups while residing in these habitats. Thus, while my results suggest that deer utilize the landscape differently when exposed to hunting activity, there is no evidence that this resulting change in habitat use causes deer to cluster or come into more frequent contact with one another in these commonly sought-after areas.

Management Implications

Management goals can be diverse depending on the primary management objective for a region. For RAP, the foremost management goal was to protect and maintain the park's native plant communities and high quality natural areas.

Based on the findings of this study, recommendations for management activities aimed at protecting plant communities can be made. If deer seek habitats which provide dense cover or protection from deer removal in response to removal activity as observed in the current and past studies (Kammermeyer and Marchinton 1976, VerCauteren and Hygnstrom 1998, Kilpatrick and Lima 1999), we would expect to find relatively larger deer densities in areas with more dense cover or in areas which experience no or less removal pressure during the removal period. Because the deer removal program may lead to lower than expected reductions in deer densities in some areas, negative browsing effects may remain a problem. If deer continue to shift their distribution across a landscape towards densely-covered habitats or areas that receive less deer removal pressure while being hunted, it is likely that a removal program will be less effective at preserving or reestablishing natural plant communities in these recognized areas. Thus, it would be valuable for mangers to gather data regarding deer numbers in high priority protection areas as well as apply additional removal efforts in these habitats. Additional effort could be in the form of increased number of harvest permits, increased hunter density, increased removal period length, or including localized culling in these habitats.

In the future, it is possible that the spread of chronic wasting disease (CWD) may become a concern for RAP managers (Manjerovic et al. 2013). When managing for infectious disease, the same management recommendations could apply as for plant community protection but the reasons to apply the strategies are different. With increased densities of deer in densely-covered habitats or areas protected from deer removal as a result of deer removal activity, deer would likely contact each other at higher rates compared to rates expected in other areas within the region. When CWD transmission is a concern, as more potentially infectious deer utilize and reside in these sought-after habitats, there is a higher likelihood for not only direct but indirect transmission of CWD as the result of greater infectious prion deposition and environmental contamination load in these recognized areas (Mathiason et al. 2006, 2009; Haley et al. 2009, Tamgüney et al. 2009, Almberg et al. 2011). Thus, management could focus removal efforts in habitats that deer prefer and therefore, mitigate direct transmission and environmental contamination.

Because deer removal programs are most frequently implemented as an effective technique to reduce deer density in an area (Hansen and Beringer 1997, Kilpatrick and Walter 1999, McDonald et al. 2007), it will be advantageous for land managers to gather data regarding the response of deer in their area following deer removal. With data in hand, managers can better mitigate the potential adverse effects caused by changes in deer habitat use when trying to maximize a hunting program's effectiveness.

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TABLES

Table 2.1. Summary of Robert Allerton Park's white-tailed deer management program data located in east-central Illinois.

Fiscal Year	Total Deer in PCSA[a] Survey (Number of repeated surveys used in analysis)	Survey Methods	Harvest Quota/Goal[b]	Deer Removed	Deer Removal Method
1988	119 (1)	Visual[c]	None	0	None
1989	188 (1)	Visual	None	0	None
1990	No Survey	NA	None	0	None
1991	No Survey	NA	None	0	None
1992	154 (1)	Visual	None	0	None
1993	176 (1)	Visual	None	0	None
1994	235 (1)	Visual	None	0	None
1995	240 (1)	Visual	None	0	None
1996	238 (1)	Visual	None	0	None
1997	226 (1)	Visual	None	0	None
1998	247 (1)	Visual	None	0	None
1999	371 (1)	Visual	None	0	None
2000	372 (1)	Visual	None	0	None
2001	264 (1)	Visual	None	0	None
2002	320 (1)	Visual	None	0	None
2003	571 (1)	Visual	None	0	None
2004	730 (1)	Visual	None	0	None
Mean	**297**			**0**	

a. PCSA stands for the Piatt County Survey Area which is 7,300 acres and includes Robert Allerton Park, a 4-H Memorial Camp, University of Illinois-owned farms, Illinois Department of Natural Resources land, and multiple private properties

b. Robert Allerton Park's deer management program set strict deer quotas for fiscal years 2005-2007. After, more lenient goals were established

c. Visual counts were completed by two observers in an aircraft

d. Counts from images obtained with a Forward Looking Infrared (FLIR) camera in an aircraft

Table 2.1 continued. Summary of white-tailed deer management program data at Robert Allerton Park located in east-central Illinois.

Fiscal Year	Total Deer in PCSA[a] Survey (Number of counts used in analysis)	Survey Methods	Harvest Quota/Goal[b]	Deer Removed	Deer Removal Method
2005	661 (1)	Visual	None	94	Archery, Shotgun, Culling
2006	288 (1)	Visual	300	299	Archery, Shotgun, Culling
2007	388 (1)	Visual	175	137	Archery, Shotgun, Culling
2008	299 (5)	Visual, FLIR[d]	200	104	Archery
2009	198 (5)	Visual, FLIR	100	73	Archery
2010	202 (1)	Visual	50-75	72	Archery
2011	292 (2)	Visual	50-75	78	Archery
2012	No Survey	NA	50-75	79	Archery
2013	113 (2)	FLIR	50-75	77	Archery
2014	No Survey	NA	50-75	52	Archery
2015	141 (1)	Visual	35-50	49	Archery
2016	No Survey	NA	35-50	49	Archery
Mean	**287**			**97**	

a. PCSA stands for the Piatt County Survey Area which is 7,300 acres and includes Robert Allerton Park, a 4-H Memorial Camp, University of Illinois-owned farms, Illinois Department of Natural Resources land, and multiple private properties

b. Robert Allerton Park's deer management program set strict deer quotas for fiscal years 2005-2007. After, more lenient goals were established

c. Visual counts were completed by two observers in an aircraft

d. Counts from images obtained with a Forward Looking Infrared (FLIR) camera in an aircraft

Table 2.2. Statistical results from a generalized linear mixed model used to predict white-tailed deer count in dry mesic upland forest, wet mesic floodplain forest, and developed habitats within Robert Allerton Park in east-central Illinois.

Parameter	Degrees of Freedom	*P*-value[a]
Habitat type	6, 20	0.04
Harvests	1, 545	<0.0001
Harvests*Habitat type	5, 545	<0.0001

a. P-values < 0.05 indicate that the parameter effect was significant in the model

Table 2.3. Mean white-tailed deer counts and mean counts weighted by habitat area for periods prior to and concurrent with Robert Allerton Park's white-tailed deer management program in east-central Illinois. The percent change in mean deer count within each habitat type between the no-removal and removal periods is indicated by the percent decrease in mean count columns.

	Mean deer count			**Deer count weighted by area of habitat**			
	Years prior to deer removal (1988-2004)	Years concurrent with removal (2005-2015)	Percent decrease in mean count	Total Acres	Years prior to deer removal (1988-2004)[a]	Years concurrent with removal (2005-2015)[a]	Percent decrease in mean count
Grade A dry mesic habitat	4.9	0.9	82.45%	82.7	5.9	1.0	83.05%
Grade B dry mesic habitat	3.1	0.2	93.65%	58.3	5.3	0.3	94.34%
Grade C dry mesic habitat	3.3	1.1	66.67%	215.7	1.5	0.5	66.67%
Grade D dry mesic habitat	10.5	4.9	53.33%	405.5	2.6	1.2	53.85%
Wet mesic floodplain habitat	20.7	10.0	51.55%	315	6.6	3.2	51.52%
Developed Land	7.8	4.7	39.74%	631.9	1.2	0.7	41.67%

a. Mean deer counts multiplied by 100

Table 2.4. Differences of least squares means for a habitat type-period interaction term from a generalized linear mixed model used to predict white-tailed deer count in dry mesic upland forest, wet mesic floodplain forest, and developed habitats within Robert Allerton Park in east-central Illinois.

Simple Effect Level	No removal period	Removal period	Estimate[a]	Adjusted *P* [b]
Dry Mesic A	0	1	1.890	<0.0001
Dry Mesic B	0	1	2.900	<0.0001
Dry Mesic C	0	1	1.270	0.0005
Dry Mesic D	0	1	0.910	0.029
Wet Mesic Floodplain	0	1	0.646	0.100
Developed Land	0	1	0.867	0.522

a. Estimates indicate the difference in estimated mean deer count between temporal periods within the corresponding habitat type

b. *P*-values have been adjusted for multiple comparisons (SMM). *P*-values < 0.05 indicate a significant difference between mean deer counts within the corresponding habitat between the no removal and removal periods

Table 2.5. Removal period-habitat type interaction least squares means from a generalized linear mixed model used to predict white-tailed deer count in dry mesic upland forest, wet mesic floodplain forest, and developed habitats within Robert Allerton Park in east-central Illinois.

Habitat type	Period	Estimate[a]	*P*-value[b]
Dry Mesic A	No Removal	1.0378	0.219
Dry Mesic A	Removal	-0.8521	0.337
Dry Mesic B	No Removal	0.9902	0.240
Dry Mesic B	Removal	-1.9093	0.056
Dry Mesic C	No Removal	0.8643	0.065
Dry Mesic C	Removal	-0.4055	0.415
Dry Mesic D	No Removal	1.7764	0.001
Dry Mesic D	Removal	0.8661	0.123
Wet Mesic Floodplain	No Removal	1.1499	0.008
Wet Mesic Floodplain	Removal	0.5043	0.262
Developed Land	No Removal	2.942	0.012
Developed Land	Removal	2.0747	0.080

a. Estimates indicate the estimated mean deer count given the corresponding habitat type and temporal period

b. *P*-values < 0.05 indicate a significant interaction between the habitat type and temporal period

Table 2.6. Global Moran's I annual indices for areas inside and outside of Robert Allerton Park located in east-central Illinois. Global Moran's I is a measure of spatial autocorrelation between features and which considers both features' locations and values across the study area.

Fiscal Year	In-Park Moran's I Index	Outside Park Moran's I Index
1988[a]	0.397	0.287
1989[a]	0.286	0.432
1990	NA[b]	NA
1991	NA	NA
1992[a]	0.316	0.347
1993[a]	0.419	0.269
1994	0.220	0.280
1995	0.108	0.112
1996	0.222	0.277
1997	0.141	0.147
1998	0.142	0.055
1999	0.062	0.073
2000[a]	0.535	0.438
2001	0.133	0.243
2002	0.290	0.413
2003	0.229	0.297
2004	0.245	0.270
2005	0.331	0.264
2006	0.111	0.244
2007	0.262	0.210
2008	0.145	0.269
2009	0.125	0.299
2010	0.078	0.205
2011	0.122	0.242
2012	NA	NA
2013	-0.003	0.105
2014	NA	NA
2015	0.084	0.264

a. Aerial survey's deer counts not included in spatial analysis due to inconsistencies when reporting deer locations on survey map

b. NA indicates that no aerial surveys were conducted that year

FIGURES

Figure 2.1. The Piatt County Survey Area (7,300 acres; indicated by the blue outline) situated in east-central Illinois. The study area is made up of Robert Allerton Park (1,500 acres; gold outline), the 4-H Memorial Camp (250 acres; red outline), the Illinois Department of Natural Resources property (800 acres; black outline), University of Illinois-owned farm properties (2,800 acres), and privately owned properties (2,000 acres). The PCSA's bridge boundaries (yellow pin symbols) indicate the start and finish locations for aerial surveys. Aerial surveys commenced at Bridge St. Bridge and were completed at Hogchute Bridge.

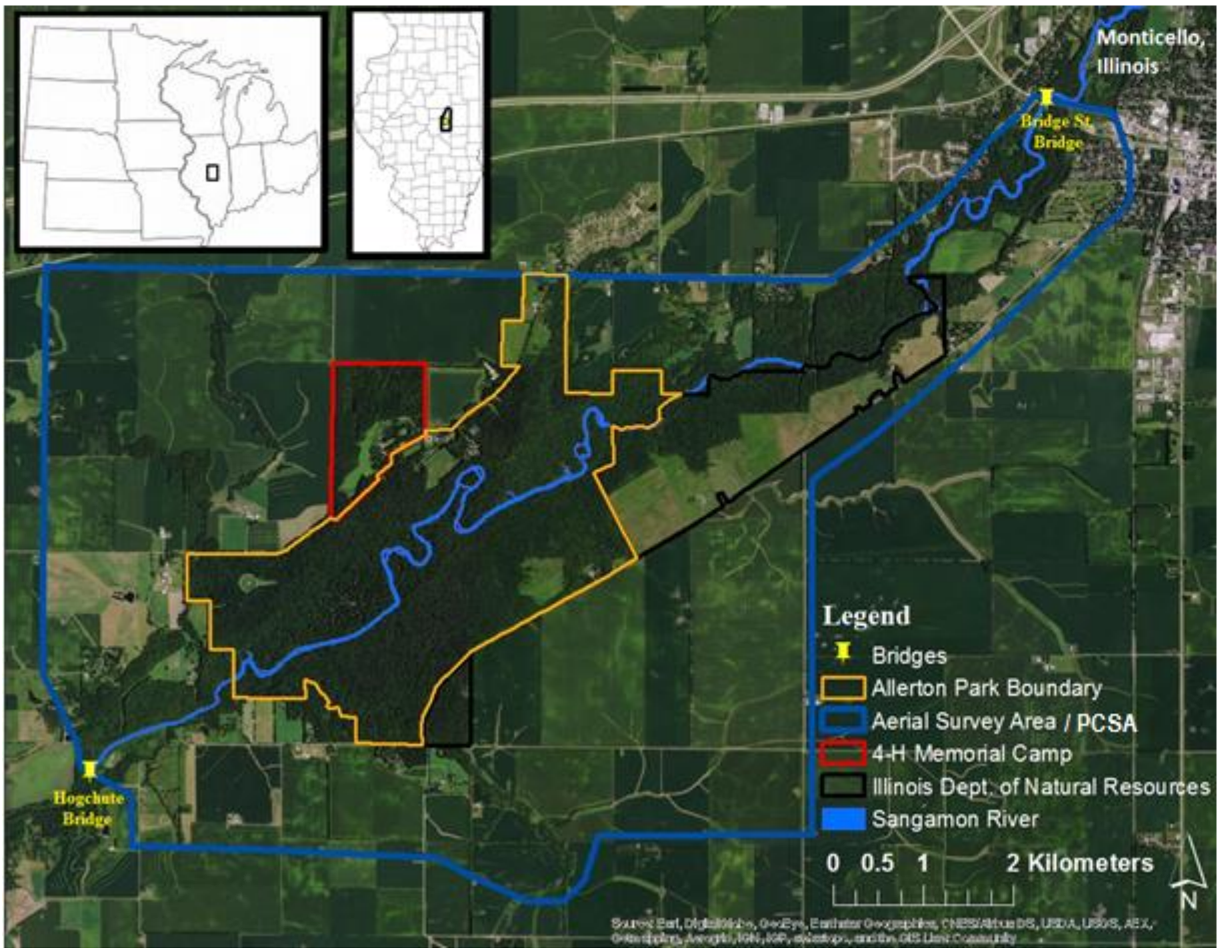

Figure 2.2. The vegetation map corresponding to the 2010 update to the Illinois Natural Areas Inventory of Robert Allerton Park's natural areas (shaded areas only) in east-central Illinois. Habitat types are labeled with a letter grade to indicate each habitat's quality.

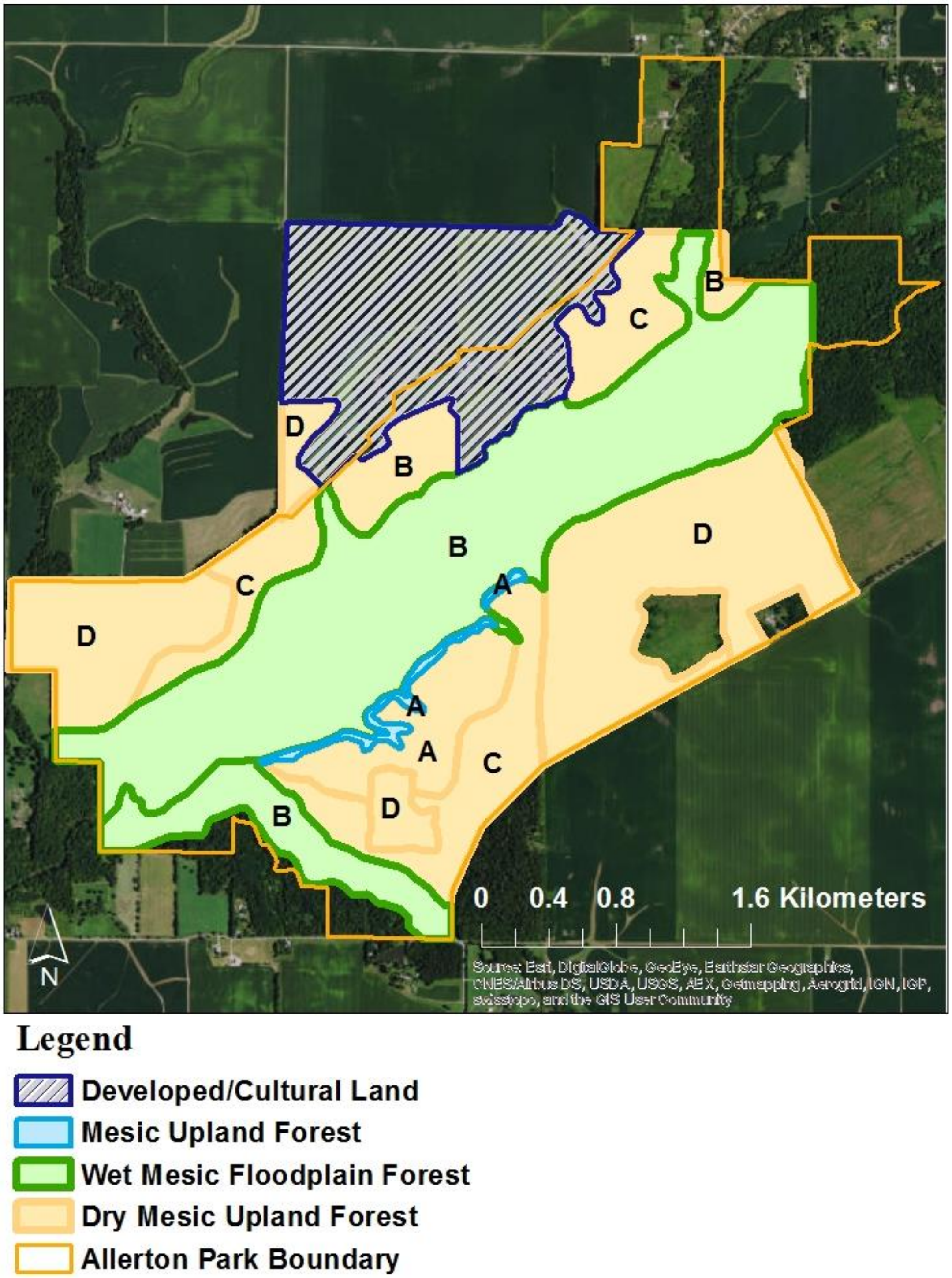

Figure 2.3. Robert Allerton Park's eight zones created in response to their white-tailed deer management program. Size (acres) of each zone and the maximum hunter density allowed based on zone size are shown. Map courtesy of John Griesbaum.

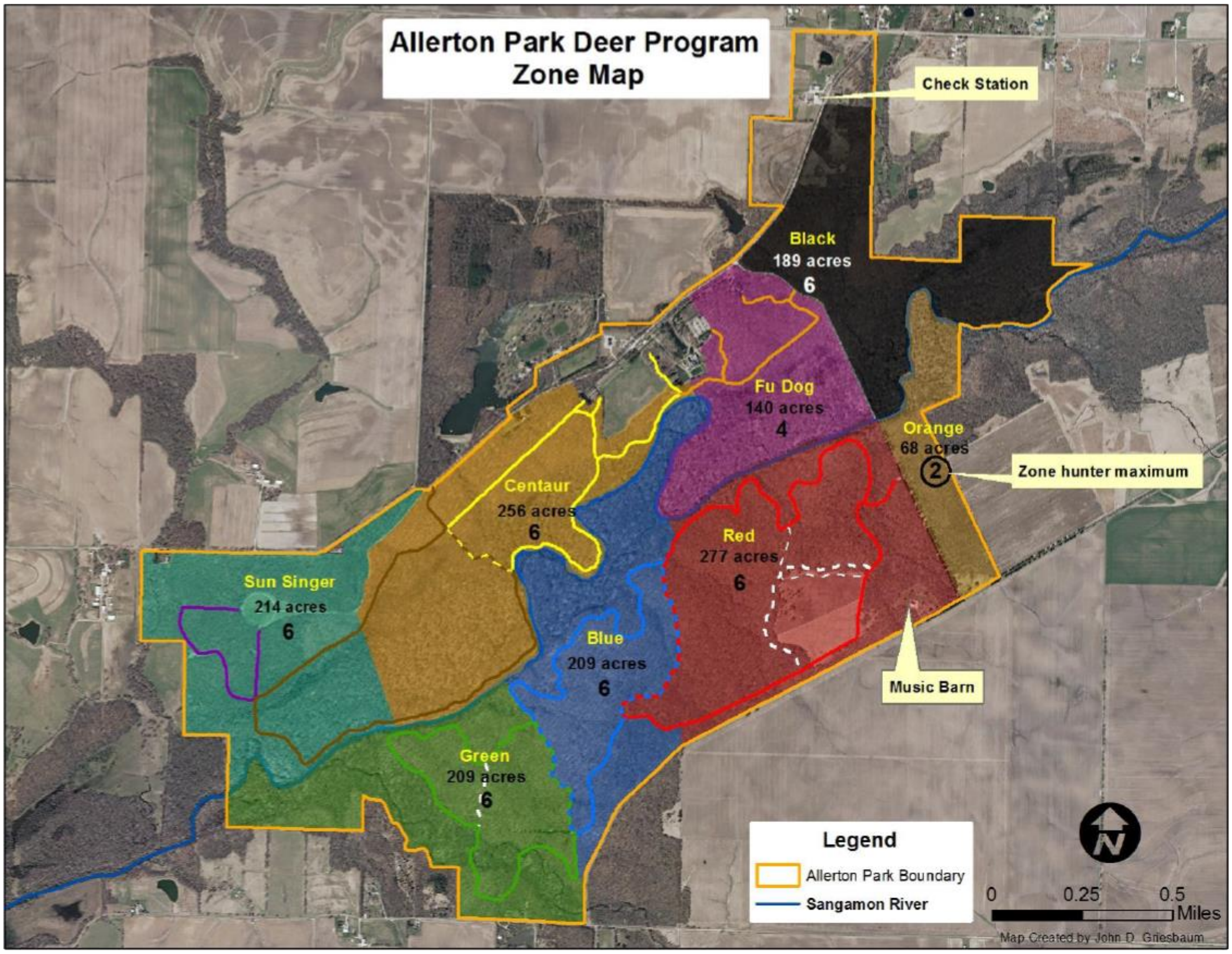

Figure 2.4. Mean white-tailed deer count for periods of no deer removal (1988-2004) and removal (2005-2015) within each of Robert Allerton Park's habitat types located in east-central Illinois.

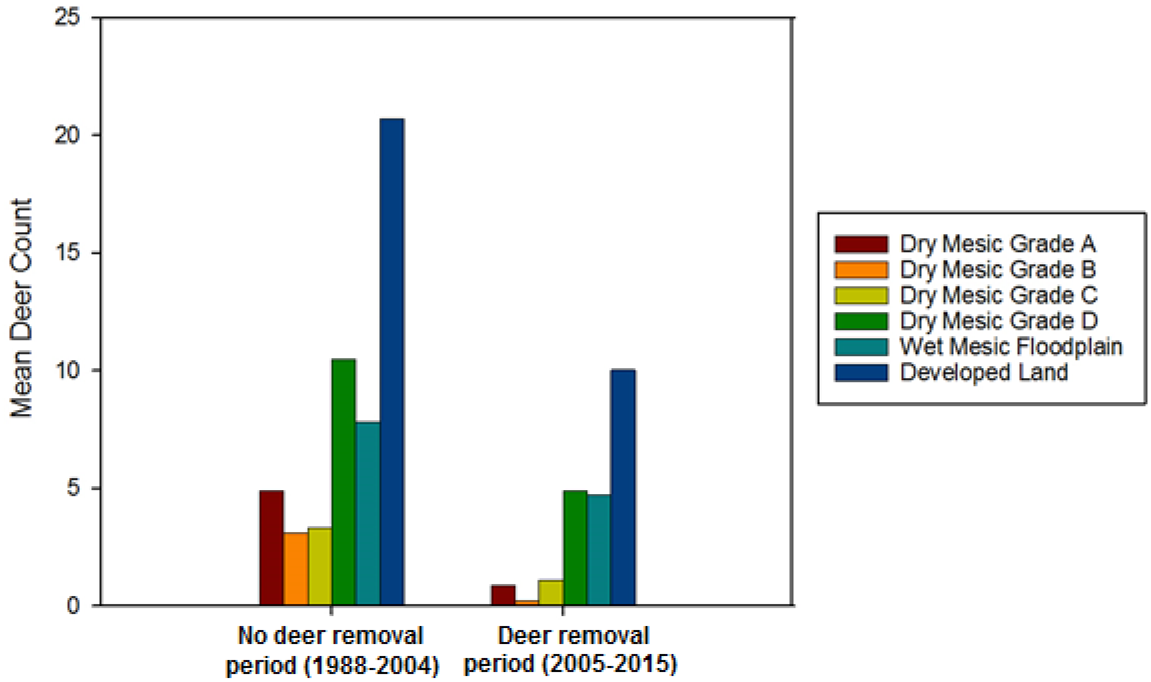

Figure 2.5. Mean white-tailed deer count per acre for periods of no deer removal (1988-2004) and removal (2005-2015) within each of Robert Allerton Park's habitat types located in east-central Illinois. Counts have been multiplied by 100.

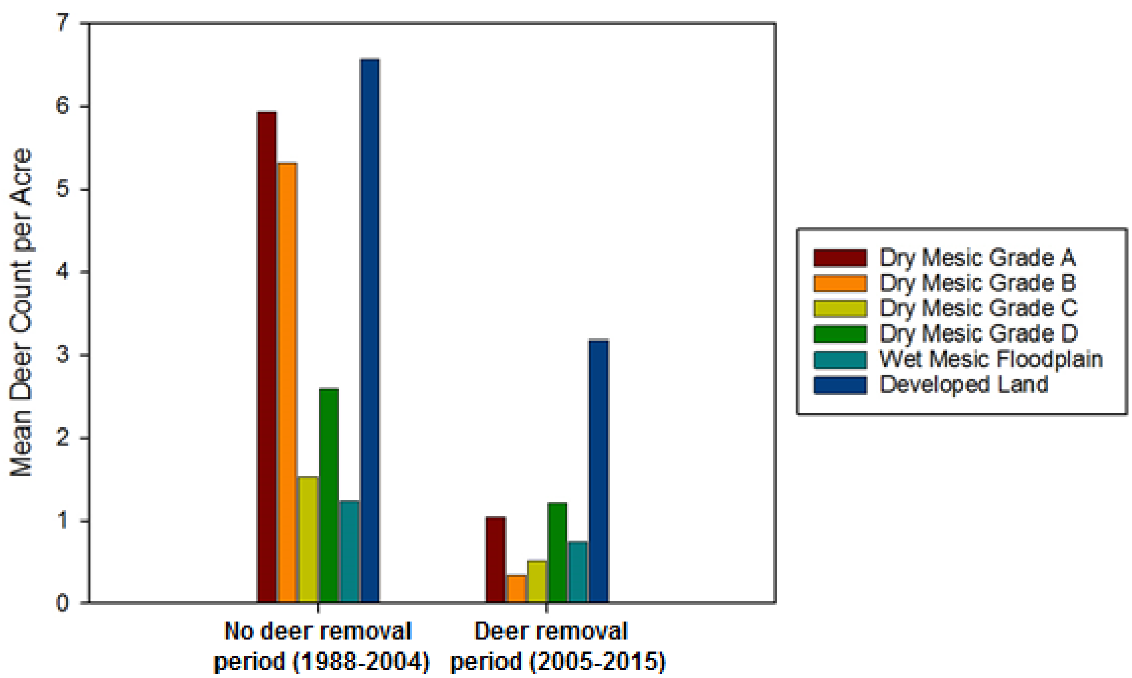

Figure 2.6. Annual Moran's I indices for white-tailed deer inside and outside of Robert Allerton Park (RAP) in east-central Illinois. The global Moran's I statistic measures spatial autocorrelation, or the amount of deer clustering across a specified area. Two trend lines are specified for each location corresponding to years prior to (1993-2004) and concurrent with (2005-2015) RAP's deer management program.

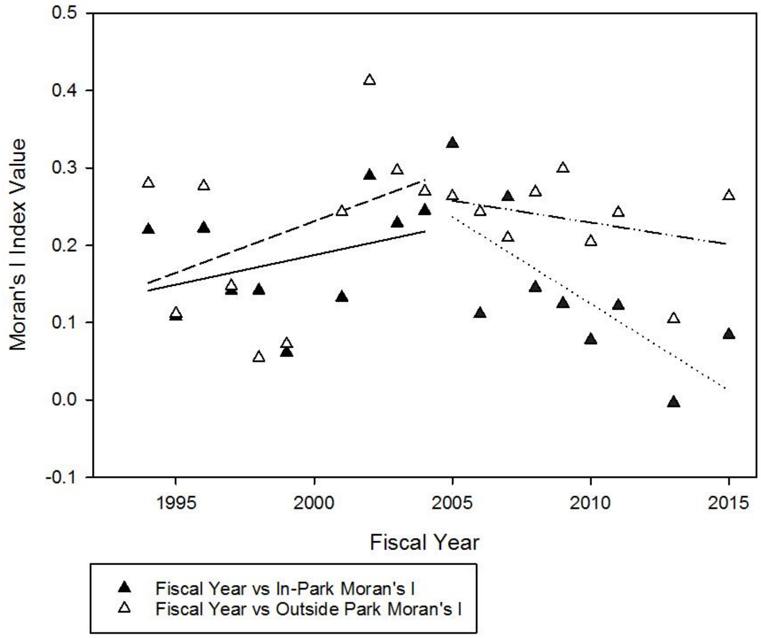

Figure 2.7. Annual white-tailed deer counts inside and outside of Robert Allerton Park in east-central Illinois based on aerial surveys conducted after each hunting season. Two trend lines are specified for each location corresponding to years prior to (1993-2004) and concurrent with (2005-2015) RAP's deer management program.

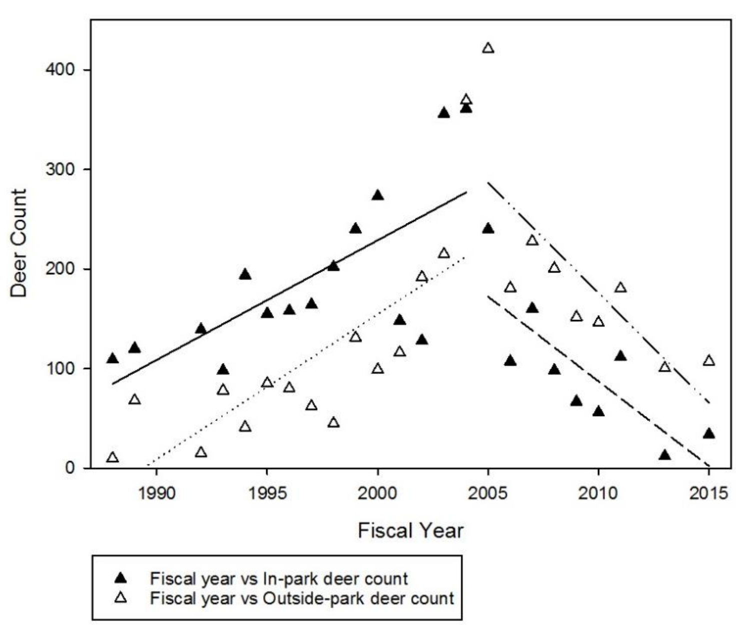

Figure 2.8. Linear regressions of white-tailed deer count by Moran's I index for regions inside and outside of Robert Allerton Park in east-central Illinois for years 1994-2015.

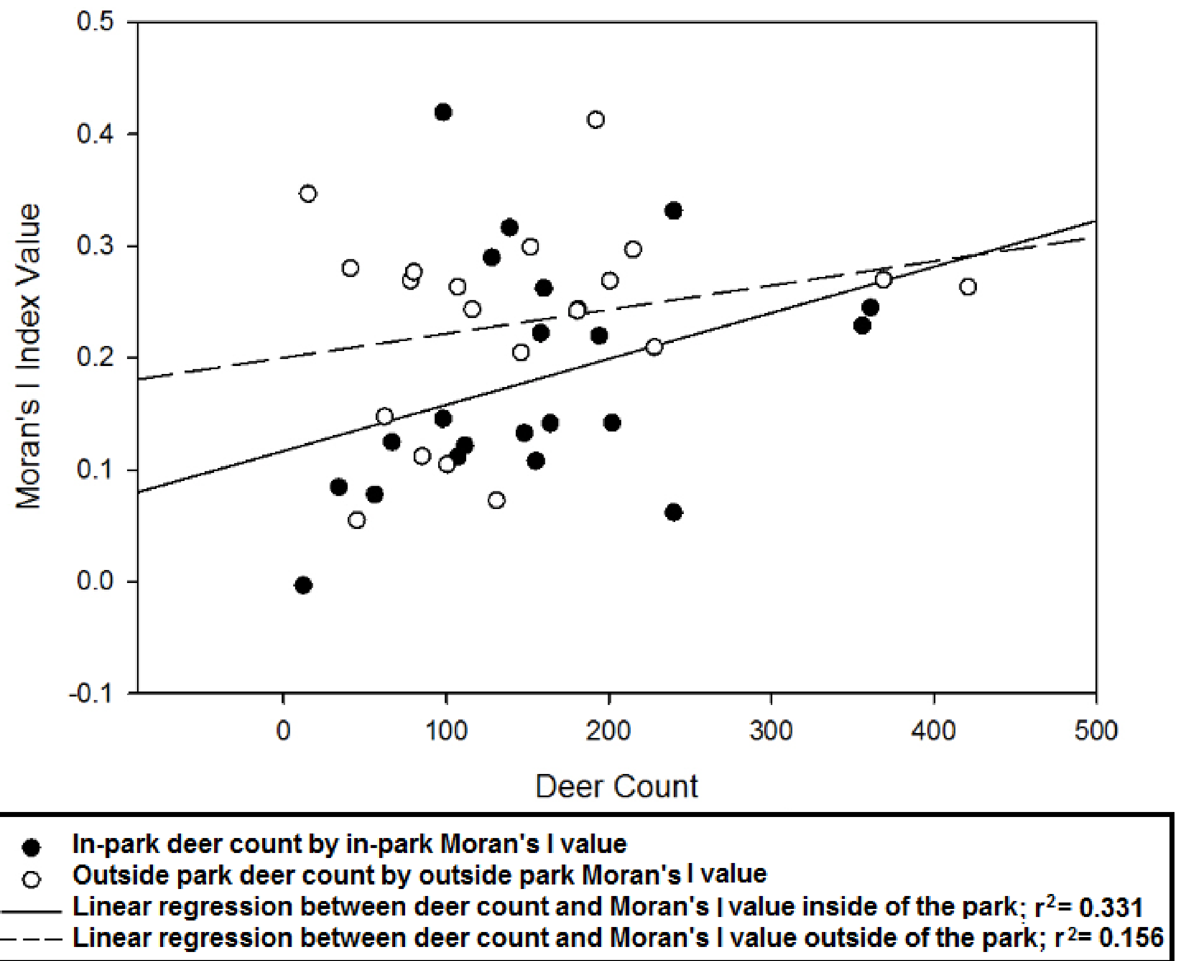

Figure 2.9. Getis-Ord General Gi* Hot Spot Analysis map covering the Piatt County Survey Area in east-central Illinois for both pre-removal (1988-2004) and removal (2005-2015) periods. Getis-Ord General Gi* identifies local areas of significant white-tailed deer clustering across the study site. Hexagonal areas consisting of 99% significant deer clusters during the pre-hunting period (1994-2004) are indicated with a pink fill color while 99% significant deer clusters during the hunting period (2005-2015) are outlined in red.