Rutgers Cooperative Extension White-Tailed Deer Drone Survey:

Hutcheson Memorial Forest and Surrounding Landscapes of Somerset County New Jersey (2019-2023)

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This study describes changes in the local white-tailed deer (*Odocoileus virginianus*) population over four years between 2019 – 2023, before and after implementing a doe-focused, community-driven deer management program. Deer per square mile density estimates were taken twice yearly at the Rutgers University Hutcheson Memorial Forest Center (HMFC) and surrounding areas of Franklin Township, Somerset County, New Jersey. These areas represent a microcosm of the New Jersey landscape consisting of residential neighborhoods, forested and agricultural lands, and open spaces, including the Spooky Brook Golf Course, Colonial Park, Delaware and Raritan Canal, and the Millstone River. Deer-related issues the community faces include damage to native plants, which leads to the spread of invasive species, deer-vehicle collisions, negative impacts on local landscapes and agricultural operations, and residential neighborhoods and public open spaces that serve as deer refuges and present challenges to management.

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Suggested Citation: Huntington, G., Paulin, J.B., and E. Huntington. NJAES (2023). *Rutgers Cooperative Extension White-Tailed Deer Drone Survey: Hutcheson Memorial Forest and Surrounding Landscapes of Somerset County, New Jersey (2019-2023).* Rutgers University, School of Environmental and Biological Sciences, New Jersey Agricultural Experiment Station, Rutgers Cooperative Extension, Hutcheson Memorial Forest Center, and Steward Green.

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Acknowledgments

This project was funded by Rutgers University, New Jersey Agricultural Experiment Station, Rutgers Cooperative Extension. Steward Green conducted all deer density surveys. The New Jersey Department of Environmental Protection Fish and Wildlife, New Jersey Farm Bureau, Franklin Township Deer Management Program, and local community members were also consulted on various aspects of the project and made valuable contributions, including facilitating access to private lands. We would also like to acknowledge the people and organizations listed below for their contributions to the project.

Gary Ambrosy, Rutgers University
Rhonda Breen-Simone, Rutgers Cooperative Extension
Central Jersey Airport
Michele Coyne, Rutgers Cooperative Extension
Franklin Township Police Department
Franklin Food Bank
Peter J Furey, New Jersey Farm Bureau
Robert M. Goodman, Rutgers University
Jason Grabosky, Rutgers University Urban Forestry Program
Hillsborough Township Police Department
Tara Kenyon, Township of Franklin Land Preservation
Ashley Kerr, New Jersey Farm Bureau
Richard G Lathrop, Rutgers University
Matthew McInerny, GIS Mapping Analyst, Steward Green
Stan Obryk, Rutgers University Institutional Planning and Operations
Nick Polanin, Rutgers Cooperative Extension
Participants of the HMFC and Rutgers University Deer Management Program
Bob Puskas, Franklin Township Open Space Committee
Jodi Powers, NJDEP Fish and Wildlife
Kevin Roche, V. Roche and Son
Maggie Roche, V. Roche and Son
Vinnie Roche, V. Roche and Son
Jenn Rogers, Steward Green
Alejandro Ruiz, Rutgers University Environmental Health and Safety
Robert Roesener, Rutgers Office of General Counsel
William Troy, Rutgers University Department of Risk Management and Insurance
Timothy Wilmot, Rutgers University Police Department
Somerset County Parks Commission
Carole Stanko, NJDEP Fish and Wildlife
Frank Toto, Franklin Township
David Tulloch, Rutgers University

Executive Summary

The Rutgers University, Hutcheson Memorial Forest Center (HMFC), is located in Franklin Township, New Jersey, and is comprised of several parcels of land totaling over 500 acres (***Figure 1***). Properties include old fields at various stages of succession, young forests, and mature primary and secondary forests surrounded by farm fields, roads, and housing developments (Aronson and Handel 2011). The site includes one of the last uncut, old-growth forests in the Mid-Atlantic, with trees over 250 years old. The forest is home to more than 350 species of plants, and 200 species of birds (NJAES/HMFC 2020), and appears on the US National Park Service registry of National Natural Landmarks (Aronson 2016).

The HMFC is devoted to conservation and research to advance ecological understanding. Since 1955, Rutgers University and its partners have conducted long-term studies of wildlife, vegetation, and agricultural abandonment (Buell 1957). The forest and surrounding areas are among the most studied ecosystems in North America, with more than 250 associated scientific publications cataloging changes in flora and fauna over time (NJAES/HMFC 2020).

Like many forests in New Jersey, since the late 1970s, deer herbivory has threatened the Hutcheson Memorial Forest by changing the structure and composition of the understory, leading to an invasion of non-native plants (Aronson 2016). Since 1979, deer herbivory has increased and led to changes in the structure and composition of the forest contributing to the invasion of non-native species threatening the forest ecosystem. Garlic mustard (*Alliaria petiolata*) and Japanese stiltgrass (*Microstegium vimineum*) inhibit forest regeneration by outcompeting native wildflowers and tree seedlings (Aronson 2016). Storms and the death of old trees have created gaps in the canopy. In a healthy forest, these gaps would infill with canopy saplings and sub-canopy species but are now dominated by invasive species such as Japanese angelica tree (*Aralia elata*), multiflora rose (*Rosa multiflora*), and wineberry (*Rubus phoenicolasius*) (Aronson 2016).

Development in the state has created fragmented landscapes and areas that can serve as wildlife refuges, often inaccessible to hunting that controls deer numbers. A deer refuge is an area of publicly or privately owned land with suitable habitat where the ability to manage deer is limited or restricted (Drake et al. 2002; Department of Environmental Protection, Division of Fish, Game and Wildlife 1999). The areas surrounding the Hutcheson Memorial Forest include residential, forested, agricultural, commercial, public, and private lands. Many of these properties do not have any programs for managing deer. These lands, including the HMFC properties prior to 2019, act as deer refuge areas. Deer often stay in these areas during the day and feed in the surrounding lands and farm fields at night, causing tremendous crop damage. Previous research conducted by the New Jersey Agricultural Experiment Station of just 27 farmers throughout the state revealed that deer-related crop damage, losses from abandoning preferred crops and fields, and the implementation of management programs totaled nearly $1.3 million (Paulin et al. 2022). Suburban communities with high deer densities that serve as refuge areas, and where hunting is not possible, may apply for a NJDEP Fish and Wildlife, Community-Based Deer Management Permits https://www.nj.gov/dep/fgw/cbdmp.htm .

Management objectives for deer in suburban areas are commonly less than 20 deer per square mile (Boulanger et al. 2014). Deer densities of less than 15 deer per square mile have been recommended to reduce negative impacts from deer browsing on woody and herbaceous plants (Waller and Alverson 1997). However, densities of 10 deer per square mile are recommended to maintain benefits for social, economic, and ecosystem integrity (Kelly 2019). Further, situations are site-specific, no density estimate recommendation translates to all areas, and managers should recognize the importance of reducing negative impacts instead of an arbitrary reduction in deer numbers (Boulanger et al. 2014). There is no magic number, and depending on the situation, even a small number of deer can cause intolerable levels of damage. An additional consideration for deer management is that adult does can produce two, and sometimes three, fawns per year under ideal conditions (Boulanger et al. 2014). Accordingly, efforts to reduce deer numbers should focus on the removal of female deer.

Management activities to protect the HMFC from deer damage began in 2015, with the construction of a fence around 85 acres, followed by the initiation of a community-based, doe-focused, volunteer bowhunting program in 2019. A monitoring program involving drone surveys was implemented prior to the start of the management hunt in November 2019. Pre-hunt surveys revealed that density estimates in the area were nearly 150 deer per square mile (NJAES/HMFC/SG 2020) and greatly exceeded the recommended levels of 10 deer per square mile (Kelly 2019).

Since the Fall of 2019, infrared drone surveys have been conducted to provide snapshots in time of the white-tailed deer density per square mile before and after community-driven, doe-focused, bowhunting seasons for the Rutgers University HMFC in Franklin Township, Somerset County, New Jersey. The full study area encompasses nearly seven square miles of a suburban-agricultural matrix interrupted by forest fragments, minimal open water as well as tributary streams to the Millstone River, a transmission line right-of-way (ROW), and several main roads, including the stretch of Amwell Road from Millstone to Cedar Grove Lane. The study area includes Colonial Park and Spooky Brook Golf Course to its northern extent and a portion of Six Mile Run to its southern extent (***Figure 1***).

Between the fall of 2019 and spring of 2023, the management and monitoring collaboration involving the New Jersey Agricultural Experiment Station, Rutgers Cooperative Extension, Hutcheson Memorial Forest Center (HMFC), Steward Green, and the local community has shown success and observed drops in deer densities from nearly 150 deer per square mile to approximately 40 deer per square mile within the Core Study Area (***Figure 2***). The initiation of the management program and increased hunter effort and presence on the properties, especially in 2020 – 2021 during the COVID-19 pandemic, have significantly contributed to the program's success in reducing deer numbers in the area (Paulin 2023).

The community-led deer management program at the HMFC has been a success. Since the program began and deer numbers have decreased, ecologists have observed native vegetation returning to the forest. The program can serve as a model for similar areas experiencing negative impacts from overabundant deer populations. Participants in the doe-focused deer management program have been very active on the HMFC properties during bowhunting seasons and have harvested over 150 deer since the program began in 2019. Nearly 70% of the deer removed in efforts to protect native vegetation and decrease damage in the surrounding areas were female, and 85% were antlerless. An additional benefit of the program has been the donation of over 13,000 servings of protein to the Franklin Foodbank to help those in need in the community.

The drone surveys are a critical element of an overall program that is planned to include long-term research, management, and educational components. The deer management program at the HMFC will serve as a community partnership and demonstration project for decision-makers and land managers. This program will allow for the study of changes over time in white-tailed deer densities and associated damage to forest ecosystems, agricultural operations and farmers' livelihoods, residential areas, and safety concerns such as deer-vehicle collisions while implementing a doe-focused lethal deer management program utilizing volunteer bowhunters to mitigate deer damage.

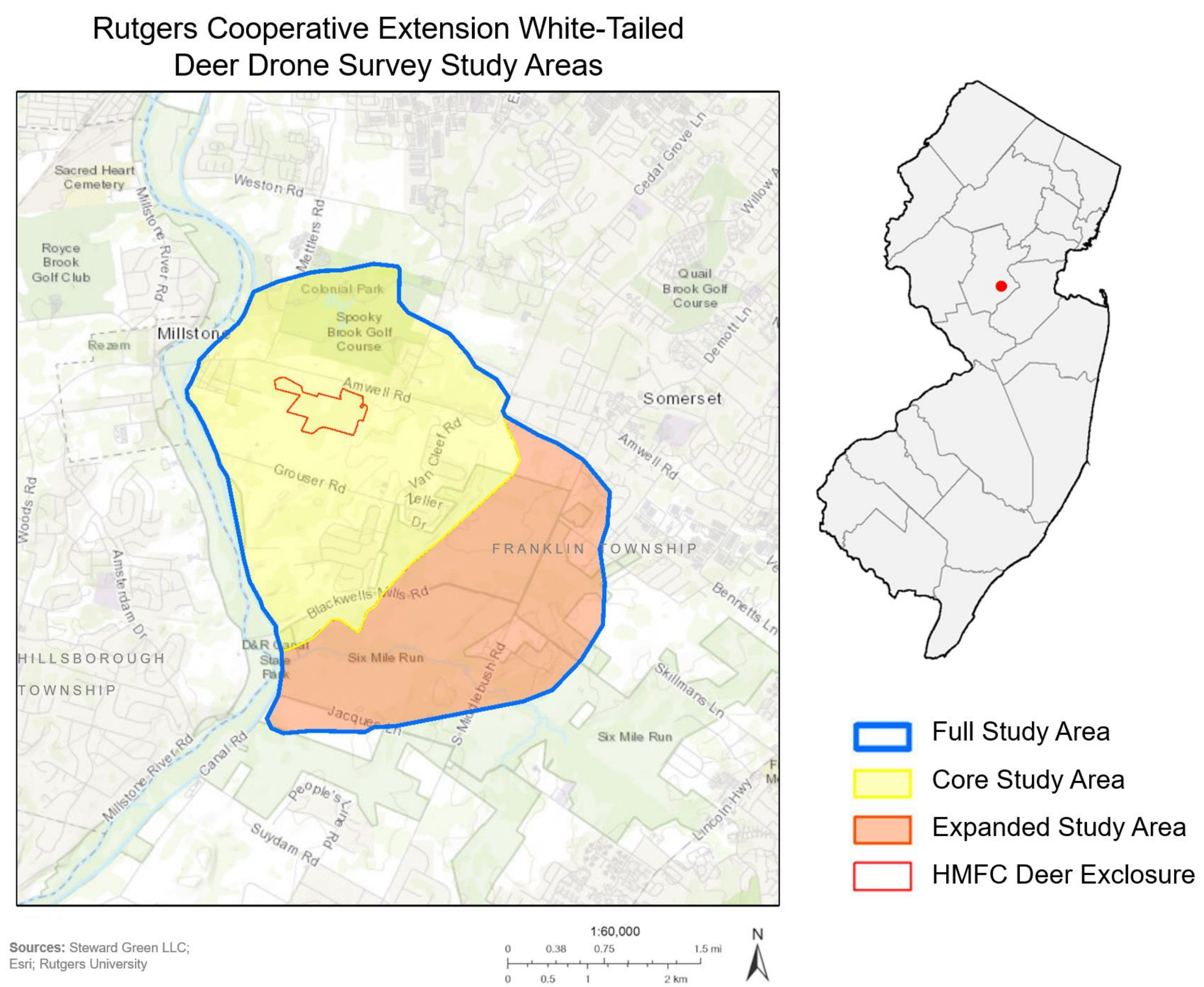

Figure 1. *Rutgers Cooperative Extension White-Tailed Deer Drone Survey Map. The full study area encompasses both Core and Expanded Study Areas, including the Rutgers University Hutcheson Memorial Forest Center (HMFC) and surrounding areas of Franklin Township, Somerset County, New Jersey.*

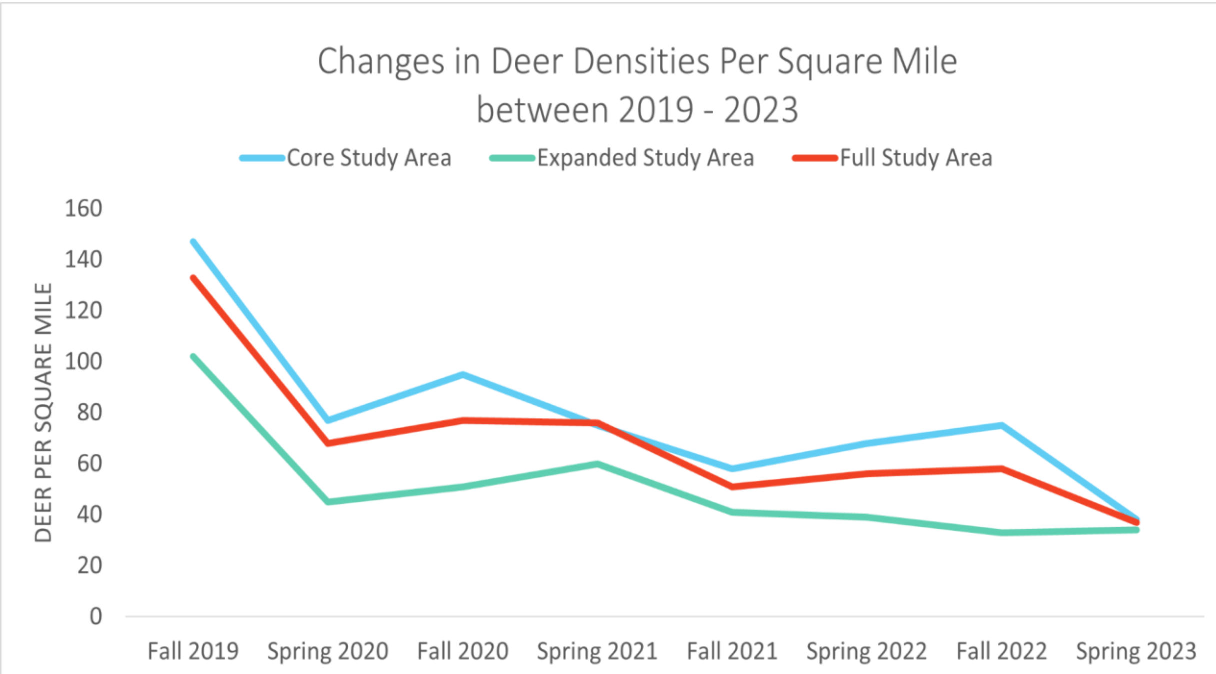

Figure 2: *Changes in deer density per square mile between 2019 and 2023 within the study areas.*

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Deer Overabundance and Damage Issues - An Overview

White-tailed deer provide many positive benefits, including wildlife viewing, photography, and recreational hunting that contribute hundreds of millions of dollars in economic benefits annually (Drake et al. 2005). They are commonly found on the edge of habitats where forested areas meet a variety of public and private lands, including agricultural areas, suburban neighborhoods, public parks, golf courses, and corporate landscapes. These fragmented landscapes, often inaccessible to hunting, a management option traditionally used to control deer numbers, can serve as wildlife refuges, and high deer densities can lead to intolerable levels of damage to native ecosystems, farmers' crops, commercial and residential landscaping and increased safety concerns from deer-vehicle collisions and tick-borne illnesses. Kelly (2019) noted impacts from increased densities of white-tailed deer of concern to forest managers in northern New Jersey that included declines in seedlings, saplings, trees, herbs, and shrubs and a shift from mostly native to exotic species. Additionally, all of New Jersey's forests are over-browsed, and in many areas, it is severe (Baiser et al 2008).

The economic impacts from unwanted deer-human interactions in New Jersey, including damage to vehicles, agricultural crops, and commercial and residential landscaping, have previously been conservatively estimated at $69,000,000 annually (Drake et al. 2005). A more recent case study of just 27 farmers throughout NJ conducted by the New Jersey Agricultural Experiment Station, Rutgers Cooperative Extension, found deer-related crop damage and "hidden costs" associated with pressure from deer, such as having to abandon fields, not being able to grow preferred crops that would increase profits, having to change crop rotations, the need for increased use of fertilizers and herbicides, and time and money spent on deer management to be $1.3 million (Paulin et al. 2022). Additionally, damage by white-tailed deer has been estimated at approximately $2 billion in the United States annually (Boulanger et al. 2014).

Management objectives for deer in suburban areas are commonly less than 20 deer per square mile (Boulanger et al. 2014). Deer densities of less than 15 deer per square mile have been recommended to reduce negative impacts from deer browsing on woody and herbaceous plants (Waller and Alverson 1997). However, densities of 10 deer per square mile are recommended to maintain benefits for social, economic, and ecosystem integrity (Kelly 2019). Further, situations are site-specific, no density estimate recommendation translates to all areas, and managers should recognize the importance of reducing negative impacts as opposed to an arbitrary reduction in deer numbers (Boulanger et al. 2014). There is no magic number, and depending on the situation, even a small number of deer can cause intolerable levels of damage. An additional consideration for deer management is that adult does can produce two, and sometimes three, fawns per year under ideal conditions (Boulanger et al. 2014). Accordingly, effort to reduce deer numbers should focus on the removal of female deer.

Agricultural Damage

Deer related agricultural damage has been described by the NJ Farm Bureau as an epidemic and was voted as the #1 issue among farmers at their 2018 and 2019 Annual Meeting. Effectively addressing damage and deer-refuges is critical to industry sustainability.

Figure 3: *Deer exclosure in a soybean field demonstrating damage to agricultural crops. Photo - Geoff Slifer.*

Excessive damage has led to field abandonment and changes in crop selection which negatively impact farmers' livelihoods.

In the late 1990s, Rutgers University conducted a study among the agricultural community due to rising losses in crop production due to deer damage. Over 2,000 responding farmers reported that deer were responsible for 70% of their wildlife-caused crop losses and that in 1997, that amount totaled between $5-10 million. Additionally, 25% of responding farmers reported abandoning fields because of excessive damage and 36% of farmers ceased growing their preferred crops as a result of excessive deer damage. In total, responding farmers expended an estimated 67,855 paid labor hours and spent $620,073 annually on attempting to control losses due to deer (Fritzell 1998).

There is also information on "hidden costs" associated with pressure from deer, such as having to abandon fields, not being able to grow preferred crops that would increase profits, having to change crop rotations, the need for increased use of fertilizers and herbicides, time and money spent on deer management, and the emotional toll it can take. Within a small pool of 27 farmers, the conservatively estimated impact of deer damage in 2019 was approximately $1.3 million. This includes direct deer damage to crops and reduced yields ($520,940) and deer-related "hidden costs" that can be assigned a dollar value ($755,200). Farmers participating in the study provided several recommendations to policymakers for enhancing deer management in the state including (1) increasing venison donation programs and helping those in need, (3) addressing residential development and the management of deer in refuge areas, (4) requiring wildlife management plans on public lands and privately leased farmlands, (5) increasing education and outreach programs on deer management for policymakers and communities, (6) providing assistance for deer fencing, (8) enhancing deer management through hunting controlled hunting programs, and (7) facilitating the implementation of farmer depredation permits and associated venison donations (Paulin et al. 2022).

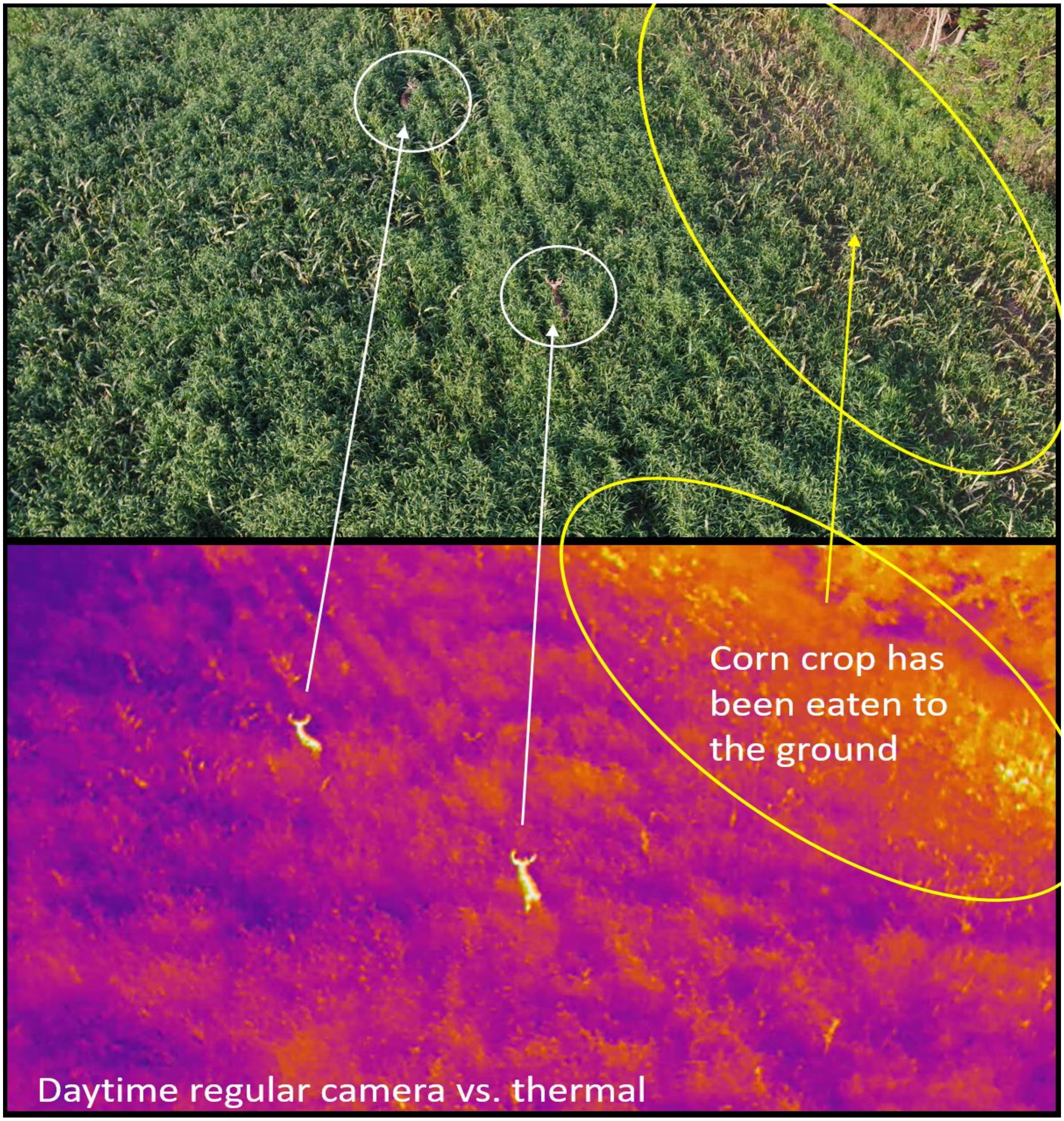


Figure 4: *Daytime regular camera vs. thermal images taken from a drone.*

Ecosystem Damage

Forest ecosystems suffer tremendously from deer *over-browsing*. Impacts to the *forest understory* start becoming harmful when population densities surpass twenty deer per square mile, impeding forest regeneration (Drake et al. 2002). All of New Jersey's forests are likely over-browsed and, in many areas, it is severe (Baiser et al 2008). Kelly (2019), noted impacts from increased densities of white-tailed deer of concern to forest managers in northern New Jersey that included declines in seedlings, saplings, trees, herbs and shrubs and a shift from mostly native to exotic species. This has been effectively demonstrated in Hillsborough, NJ through a long-term study of floral demographics throughout the implementation of deer management activities at Duke Farms Foundation. The property started out with extremely high numbers of deer, and non-native plant species. Effective management that greatly reduced deer numbers, supplemented by a deer exclosure surrounding the property, and efforts to reduce non-native flora helped to restore the forest and increased native plant species (Almendinger et al., 2020).

In other areas, deer densities of less than 15 per square mile have been recommended to reduce negative impacts from deer browsing on woody and herbaceous plants (Waller and Alverson 1997). At densities greater than 100 deer per square mile, woodlands are void of understory plants from constant deer pressure through *herbivory*. Scientists have predicted that if this trajectory of flora devastation is allowed to continue, New Jersey will lose its *native* forests in mere decades (Horsley et al. 2003). New seedlings will never become mature trees without proper regeneration in the understory. Thus, forests are lost through *attrition,* and the overall structure and composition of the vegetation changes as non-native, invasive plant species invade (Alverson et al. 1988, Cote et al. 2004, Horsely et al. 2003).

When understory habitat is disappearing, biodiversity decreases across the board, negatively affecting other species of flora and *fauna* (Horsley et al. 2003). Additionally, through the loss of *biodiversity* in these woodlands, other species suffer from the direct and indirect effects of deer overabundance (Alverson et al. 1988).

Ground nesting ovenbirds (*Seiurus aurocapilla), that eat ticks,* and other *neo-tropical migratory birds,* have less habitat, which can also contribute to population declines. Insects lose feeding species, and pollinators lose host plants and sources of nectar. When the forest understory is eaten by deer, root systems that hold soil in place decrease, causing *erosion* and increases in *sedimentation*. Native planting programs, *reforestation* and other conservation programs are also very difficult to implement with high deer densities. Failure to acknowledge these ecological connections and ignoring over-abundant deer populations works directly against conservation efforts and the preservation of natural diversity (Alverson et al. 1988).

Figure 5: *Hutcheson Memorial Forest Center research plots before and after removing invasive plant species. Photos – Scarlett Simpson.*

Hutcheson Memorial Forest Center

The Hutcheson Memorial Forest Center (HMFC), located in Franklin Township, New Jersey, comprises several parcels of land totaling over 500 acres. Properties include old fields at various stages of succession, young forests, and mature primary and secondary forests surrounded by farm fields, roads and housing developments (Aronson and Handel 2011). The site includes one of the last uncut, old growth forests in the Mid-Atlantic with trees over 250 years old. The forest is home to more than 350 species of plants, 200 species of birds (Hutcheson Memorial Forest Center 2020) and appears on the US National Park Service registry of National Natural Landmarks (Aronson 2016).

Figure 6: *Hutcheson Memorial Forest Center research plots before and after removing invasive plant species in the forest understory. Photos - Joseph Paulin.*

The HMFC is devoted to conservation and research to advance ecological understanding. Since 1955, Rutgers University and partners have conducted long-term studies of wildlife, vegetation and agricultural abandonment (Buell 1957). The forest and surrounding areas are among the most studied ecosystems in North America with more than 250 associated scientific publications cataloging changes in flora and fauna over time (Hutcheson Memorial Forest Center 2020).

Since 1979, deer herbivory has increased and led to changes in the structure and composition of the forest contributing to the invasion of non-native species threatening the forest ecosystem (Brown 2019, Aronson 2007). Garlic mustard (*Alliaria petiolata*) and Japanese stiltgrass (*Microstegium vimineum*) inhibit forest regeneration by outcompeting native wildflowers and tree seedlings (Aronson 2016). Storms and the death of old trees have created gaps in the canopy. In a healthy forest these gaps would infill with canopy saplings and sub-canopy species, but are now dominated by invasive species such as Japanese angelica tree (*Aralia elata*), multiflora rose (*Rosa multiflora*) and wineberry (*Rubus phoenicolasius*) (Aronson 2016).

Safety Concerns

Vehicular accidents caused by deer cost New Jersey residents millions of dollars in insurance claims annually and sometimes end in human fatality (Jennings 2017, Sherman 2018). Approximately 25,000 deer-vehicle collisions take place in New Jersey each year with insurance payouts of over $100 million (State Farm Insurance 2016). Even though the number of claims in NJ is extremely high, many of the minor accidents don't even get reported. Somerset County remains one of the highest vehicular accident counties related to deer in New Jersey, ranked No. 11 in the state (Sherman 2018). Hillsborough Township, located in Somerset County, New Jersey, ranked No. 1 with the most reported vehicular accidents related to deer in 2017 (Sherman 2018).

Figure 7: *White-tailed deer hit by a vehicle across the street from the Hutcheson Memorial Forest Center on Amwell Road in Franklin Township, Somerset County, NJ. Photo - Joseph Paulin.*

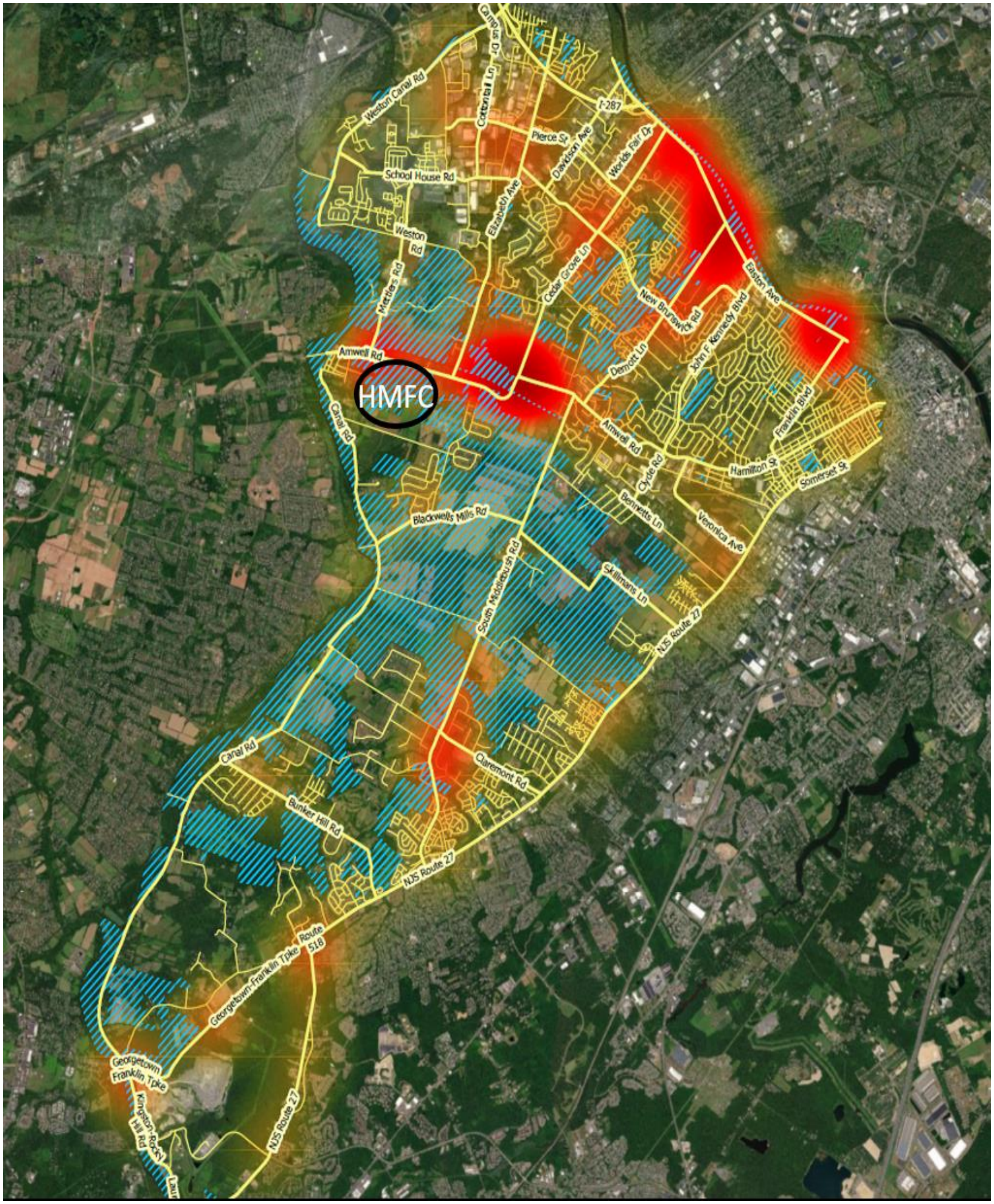


Figure 8: *Color graphic of Franklin township, Somerset, NJ, deer-vehicle collisions in the area of the Hutcheson Memorial Forest in 2017. Red areas represent hotspots for deer-vehicle collisions. Credit - Rutgers University Landscape Architecture Geodesign Studio.*

Disease Concerns

Lyme Disease is a concern for people in New Jersey with cases increasing over the last two decades. In 2017, there were 5,092 reported cases of Lyme Disease in the state, the highest yearly total in nearly two decades, according to recent data from the New Jersey Department of Health (Kent 2018) (**Figure 9)**. Ticks use deer to feed, mate, reproduce, and disperse (Cote et al. 2004, Kent 2018). With large populations of deer and dwindling habitat for insectivorous ground-nesting birds, such conditions have allowed ticks to thrive. Although deer are among many mammals that carry ticks, the white-footed field mouse is the primary vector in New Jersey.

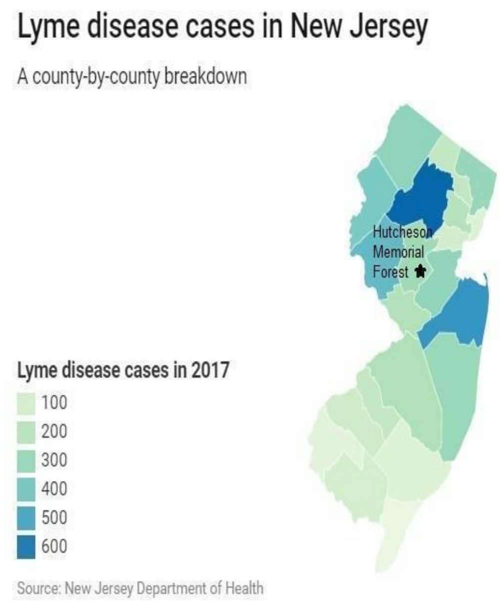


***Figure 9:** 2017 Lyme Disease cases in NJ by county. Source - NJ Department of Health.*

Development and Deer Refuges

Deer are commonly found on the edge of habitats where forested areas meet a variety of public and private lands including agricultural areas, suburban neighborhoods, public parks, golf courses and corporate landscapes. These fragmented landscapes, often inaccessible to hunting to control deer numbers, can serve as wildlife refuges that can lead to intolerable levels of damage to native ecosystems, farmers' crops, commercial and residential landscaping and increased safety concerns from deer-vehicle collisions and tick-born illnesses (Paulin et al. 2022).

A deer refuge is an area of publicly or privately owned land with suitable habitat, where the ability to manage deer is limited or restricted (Drake et al. 2002; Department of Environmental Protection, Division of Fish, Game and Wildlife 1999). Farmers have noted that as development has increased in New Jersey, starting as early as the 1970s, pressure from deer has increased. Neighborhoods, unmanaged woodlands and open spaces, are serving as refuge areas, for deer that feed in the farm fields at night and cause extensive crop damage (Paulin et al. 2022).

Policymakers, townships, and public and private land managers have the opportunity to adopt comprehensive deer management strategies to minimize deer refuges and reduce intolerable levels of deer-related damage that can negatively impact native ecosystems, agriculture and address concerns for public health and safety. To reduce deer numbers in developed and residential areas where hunting is not allowed or practical, or where hunting alone cannot remove enough deer, townships can to apply for a New Jersey Department of Environmental Protection, Fish and Wildlife, Community Based Deer Management Program permit (https://www.nj.gov/dep/fgw/cbdmp.htm). The permit allows for additional lethal management options and removal of deer outside of regulated hunting seasons. Townships can also look for opportunities to donate the venison to foodbanks to help those in need in their community.

Survey Objective

To provide long-term data on the white-tailed deer population of the Rutgers University Hutcheson Memorial Forest Center and surrounding areas of Somerset County before and after the implementation of a deer management program.

Methodology

Steward Green LLC (SG) provided Rutgers Cooperative Extension with infrared *thermal digital aerial* imagery analysis and reporting within the study areas. The intent of the data collection was to confirm deer population densities at the time of data collection. The data collection required nighttime thermal *Forward-Looking Infrared (FLIR)* aerial *photogrammetry* of the study areas, most importantly collected imagery that best indicated white-tailed deer *heat signatures*. Optimum data collection was during the night and early morning, and during colder months before the *deciduous trees* produced leaves, allowing infrared sensors penetration to the ground. The colder ground temperatures contrasted greater with heat signatures produced by deer. These infrared heat signatures produced a reliable method of "counting" the deer in analysis by an experienced technician (Drake et al. 2003). *Vertical Take-Off and Landing (VTOL) Unmanned Aerial Systems (UAS)*, or drone systems, were used legally and safely to collect the data. Flights were completed less than 400' *above ground level (AGL)*. Equipment was *calibrated* in the field to ensure geographic accuracy.

Areas Surveyed and Deer Density Estimates

Since the Fall of 2019, infrared drone surveys have been conducted to provide snapshots in time of the white-tailed deer density per square mile before and after community-driven, doe-focused, bowhunting seasons for the Rutgers University HMFC in Franklin Township, Somerset County, New Jersey. The full study area encompasses nearly seven square miles of a suburban-agricultural matrix interrupted by forest fragments, minimal open water as well as tributary streams to the Millstone River, a transmission line right-of-way (ROW), and several main roads, including the stretch of Amwell Road from Millstone to Cedar Grove Lane. The study area includes Colonial Park and Spooky Brook Golf Course to its northern extent, and a portion of Six Mile Run to its southern extent (**Figure 10**). Vegetation consisted of a mix of upland woodland and meadows, often surrounded by agricultural fields, residential areas, fragmented woodland parcels, wetlands and open water. Infrastructure such as utility lines, rights-of-way, roads, housing and mixed-use developments were also included in the study area.

The **Core Study Area** is 3.99 square miles (2,554 acres) and encompasses the HMFC and the surrounding areas of Franklin Township. Utilizing the Delaware and Raritan Canal as its western border. The Core Study Area can be roughly delineated by Canal Road (west), down to Blackwells Mills Road (south), to just beyond Van Cleef Road (east), and nearly up to Weston Road (north). This area has remained constant throughout all drone survey events from 2019 to 2023. The results in this area are comparable across all years.

Over the course of the eight completed drone surveys, parts of the full study area have changed slightly. The first two drone surveys in the fall of 2019 and spring of 2020 included coverage in Hillsborough Township immediately to the west of the Millstone River. To include additional agricultural areas, the southeastern borders were expanded in the fall of 2020. This **Expanded Study Area** refers to an additional 2.78 square miles (1,779 acres) to the south and southeast, including Six Mile Run with Jacques Lane as its southern border and reaches beyond South Middlebush Road to the east (**Figure 10**).

Multiple missions were flown in both the Core and Expanded Study Areas for total coverage. Separate deer counts and density estimates were calculated for each area of the overall study area. Deer densities were calculated by dividing the total number of confirmed deer confirmed by the size of the area surveyed.

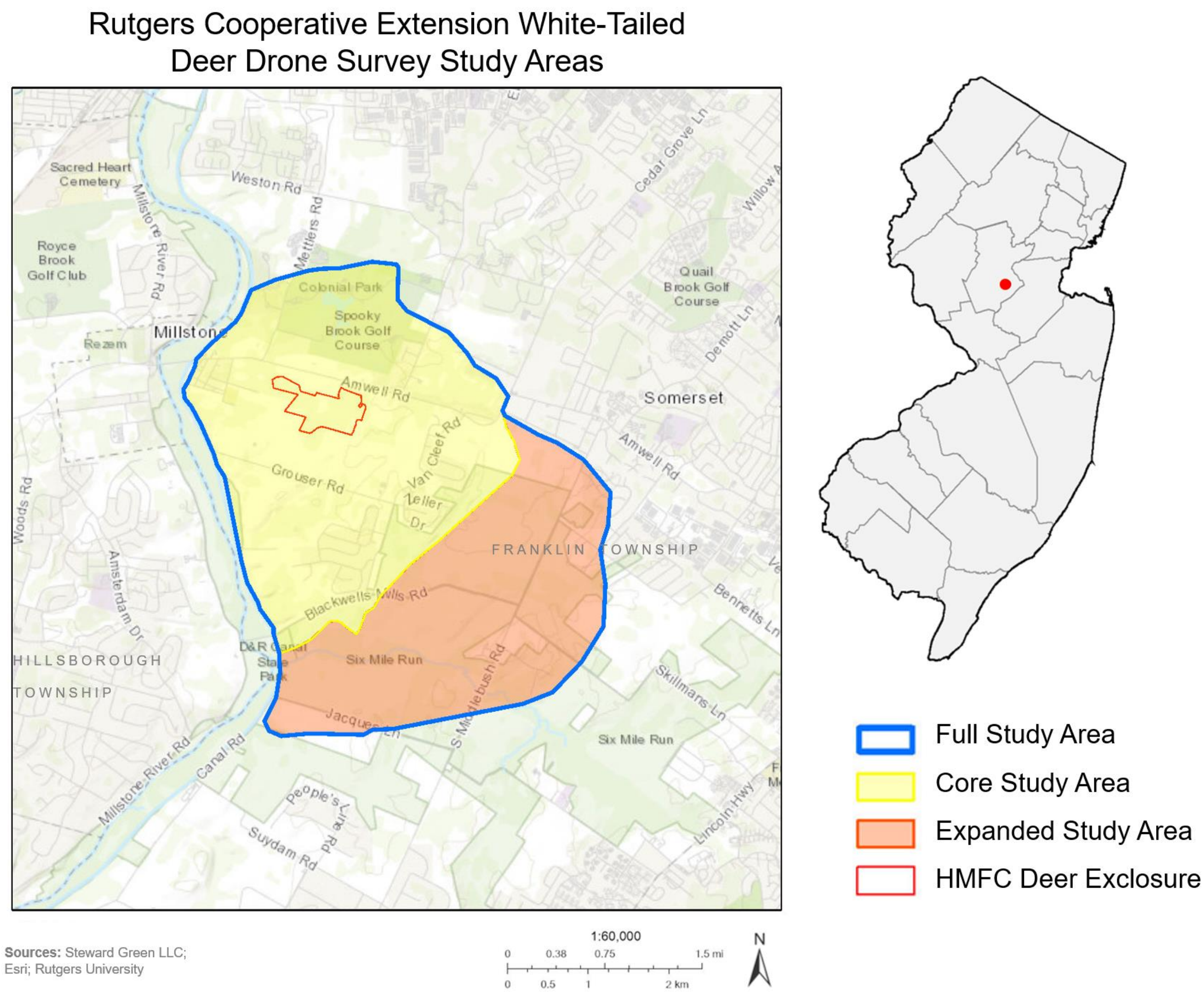


__Figure 10:__ Rutgers University white-tailed deer drone survey study areas. The full study area encompasses both the Core and Expanded Study Areas, including the Rutgers University Hutcheson Memorial Forest Center (HMFC) and surrounding areas of Franklin Township, Somerset County, New Jersey.

Pre-Survey Preparation

Pre-survey site reconnaissance included mandatory Federal Aviation Administration (FAA) daytime inspections of the project area to evaluate *ingress* and *egress*, potential launch and landing points, site hazards, obstructions, and flight patterns. Changes in elevation, large trees, high voltage electric lines, and cell phone, radio, and water towers were also identified. Launch and landing sites were pre-determined before any flights were conducted. Community members and the NJAES, RCE, and HMFC teams familiar with the area participated in the surveys and facilitated access to launch sites on private lands (***Figure 11).***

Drone pilots were approved to perform UAS operations based on certifications with the *Federal Aviation Administration* (FAA) and standard procedures. The *missions* (flights) were performed legally and safely below 400 feet Above Ground Level (AGL), or less than 400 feet above any object (mountains, trees, towers, poles or electric lines) located within the survey area. Before any *small Unmanned Aerial System* (sUAS) flights were conducted, pilots determined there were no *Temporary Flight Restrictions* (TFRs) issued by FAA. The surveys were conducted at night with the required FAA nighttime pilot certifications and nighttime authorization. Notifications were made to Franklin Township Police, Central Jersey Regional Airport, Somerset County Parks Commission, farmers, and neighbors in, or surrounding, the study area.

Overcount Prevention

Flights were conducted manually to produce the best results. This method allows the pilot to pause, hover, circle areas, zoom and even change the oblique sensor angle when there are questionable heat signatures behind structures, underneath cover or grouped together. This methodology also differs from traditional methods using *fixed wing* airplanes or now even drones that fly *strip transects* with fixed optics. Areas are flown systematically, reducing risk of overcounting. Groups of deer are identified and mapped in real-time. *Geo-referencing* was performed in the field for accurate locations, vegetation type and mapping. Analysis was performed both in the field and later in the lab to confirm the number of deer counted in the survey.

Figure 11: *The survey team launching a drone to conduct white-tailed deer surveys at the Rutgers Hutcheson Memorial Forest Center agricultural fields. Photo - Joseph Paulin.*

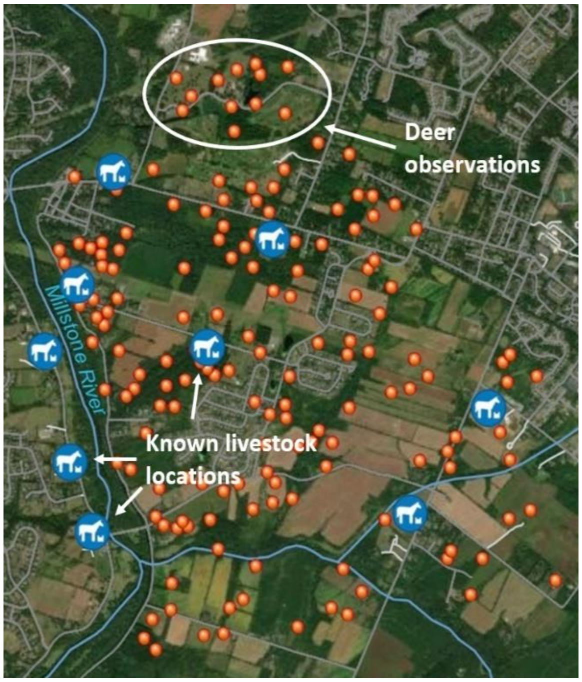


Figure 13: Graphic showing known livestock locations and examples of deer observed (red dots) during drone surveys.

Esri Data Collector was used in the field to record numbers, map geographic locations of deer and make field notes (**Figure 12**). This method is becoming increasingly more dependable for the population density data collection of *ungulates* (Chabot and Bird 2015).

Species Identification

Thermal imagery was analyzed both in the field and later in the lab to confirm deer heat signatures (**Figures 13 to 16**). Note that deer heat signatures could not always be viewed underneath evergreen trees or other obstructed areas.

A trained wildlife biologist or experienced professional performed the analysis to ensure that deer heat signatures are confirmed and distinguished from heat signatures other animals such as cattle, horses (**Figures 17 and 18**), sheep,

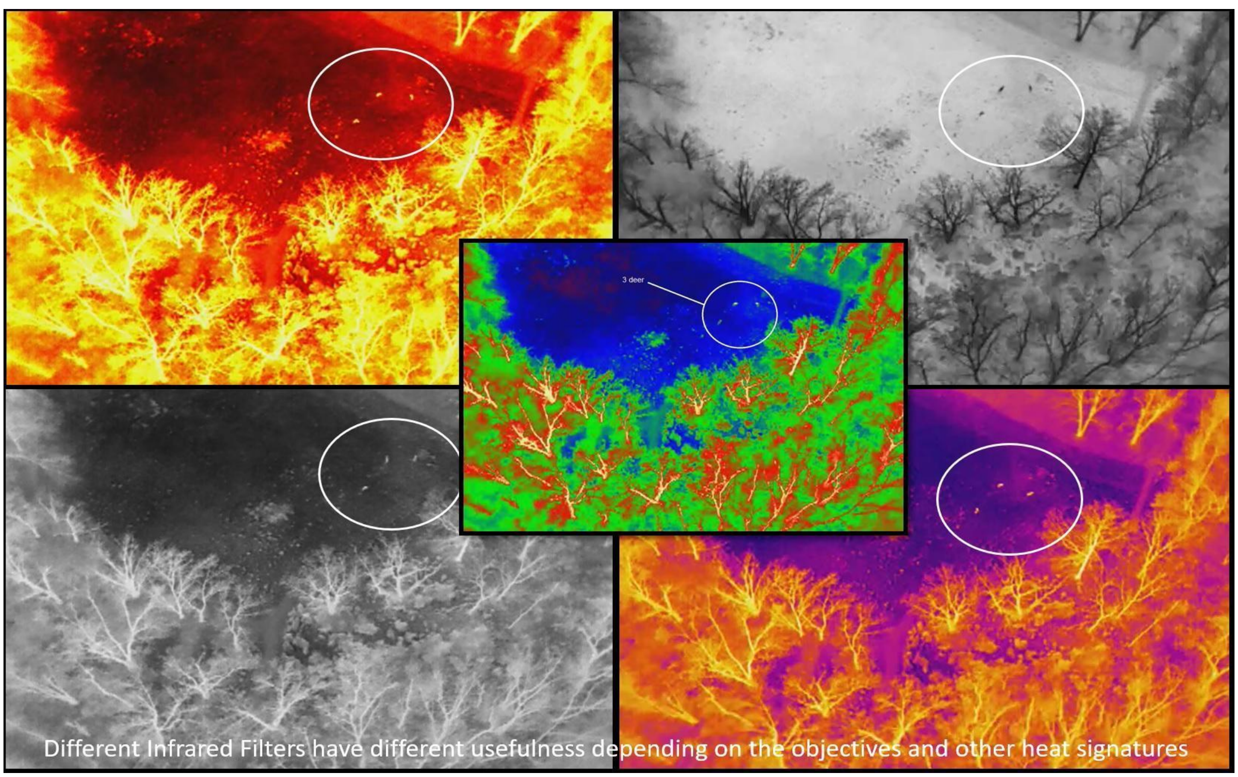


Figure 12: *Graphics showing how the same three deer appear under five different infrared filters.*

goats, fox, raccoon, and coyote. Scale, shape, location, and behavior were the main determining factors that distinguish deer from other animals. Additionally, extensive reconnaissance of the study areas was conducted in advance of the surveys identifying locations of domestic animals.

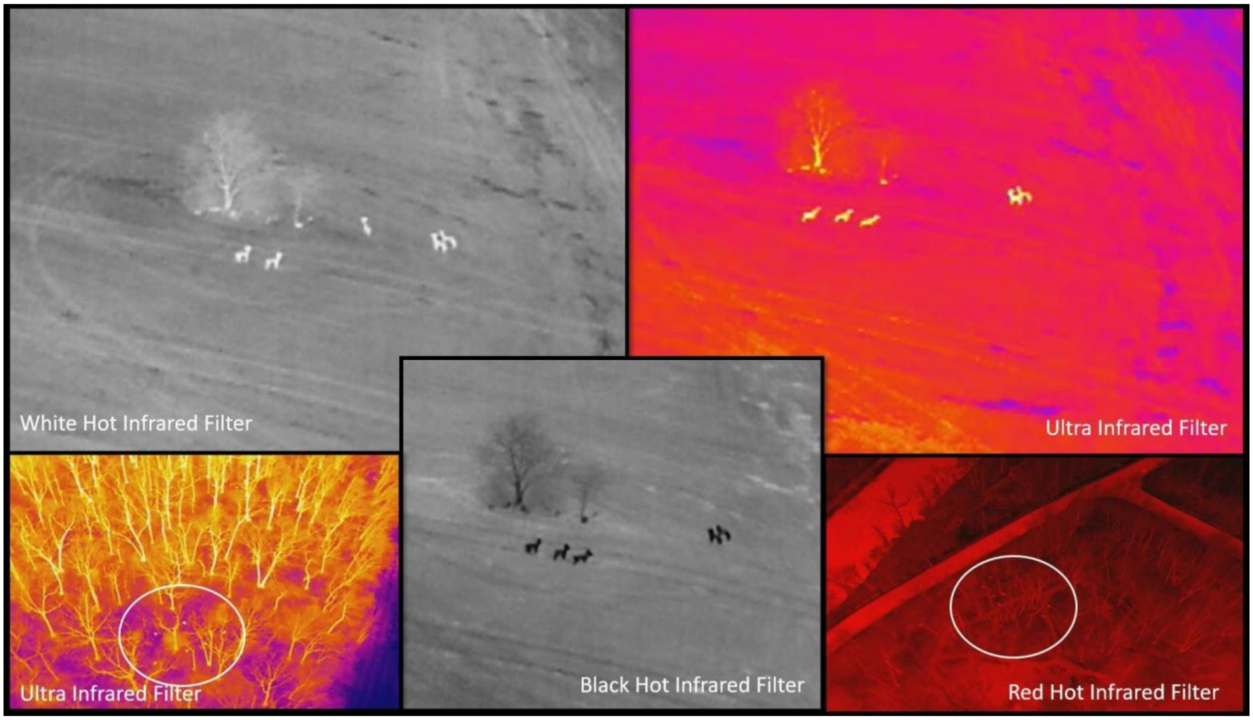


Figure 14: *Graphics demonstrating how five different infrared filters help visualize and confirm white-tailed deer's heat signatures during drone surveys.*

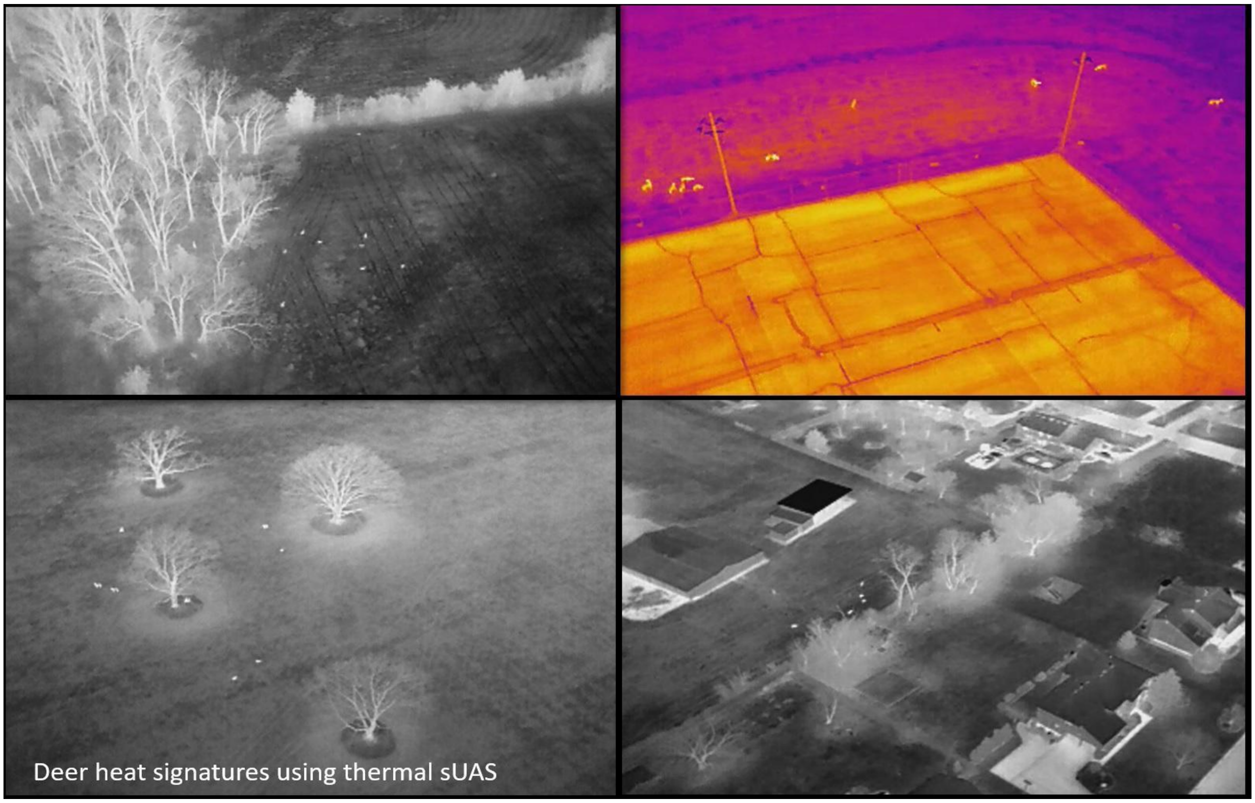


Figure 15: *Graphics demonstrating how the heat signatures used to identify deer during drone surveys were clear and visible, which helped prevent overcounting.*

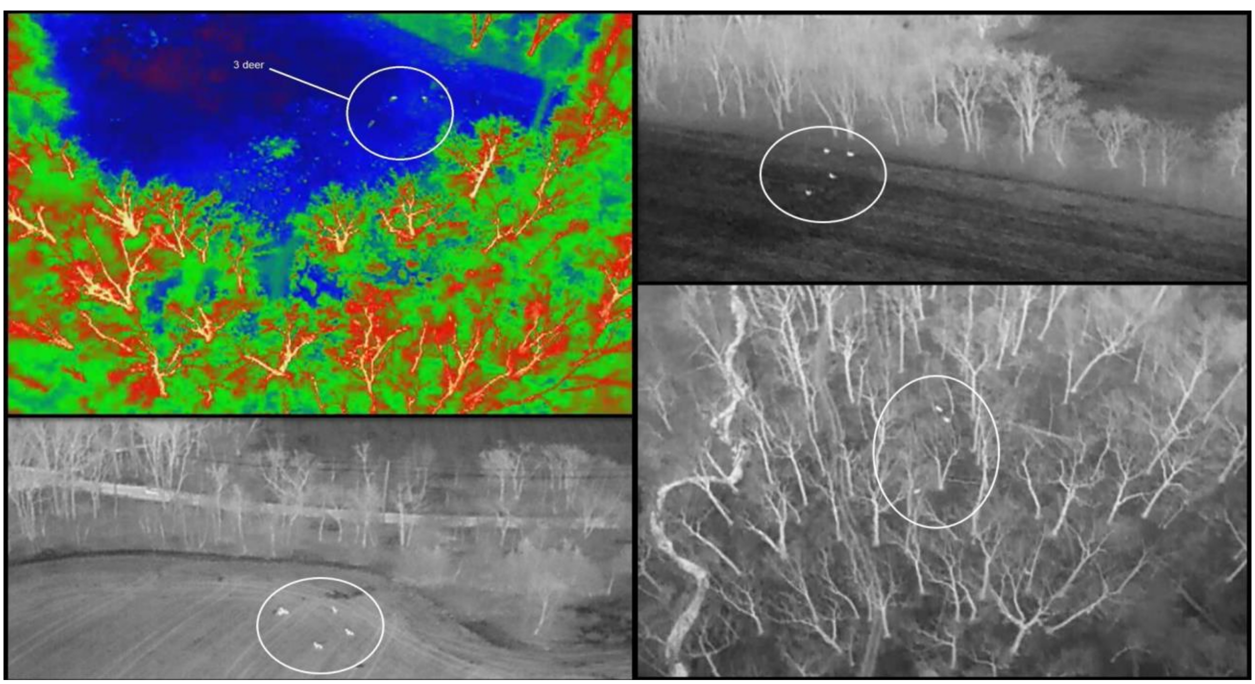


Figure 16: *Examples of heat signatures used to identify deer during drone surveys of agricultural fields and woodlands.*

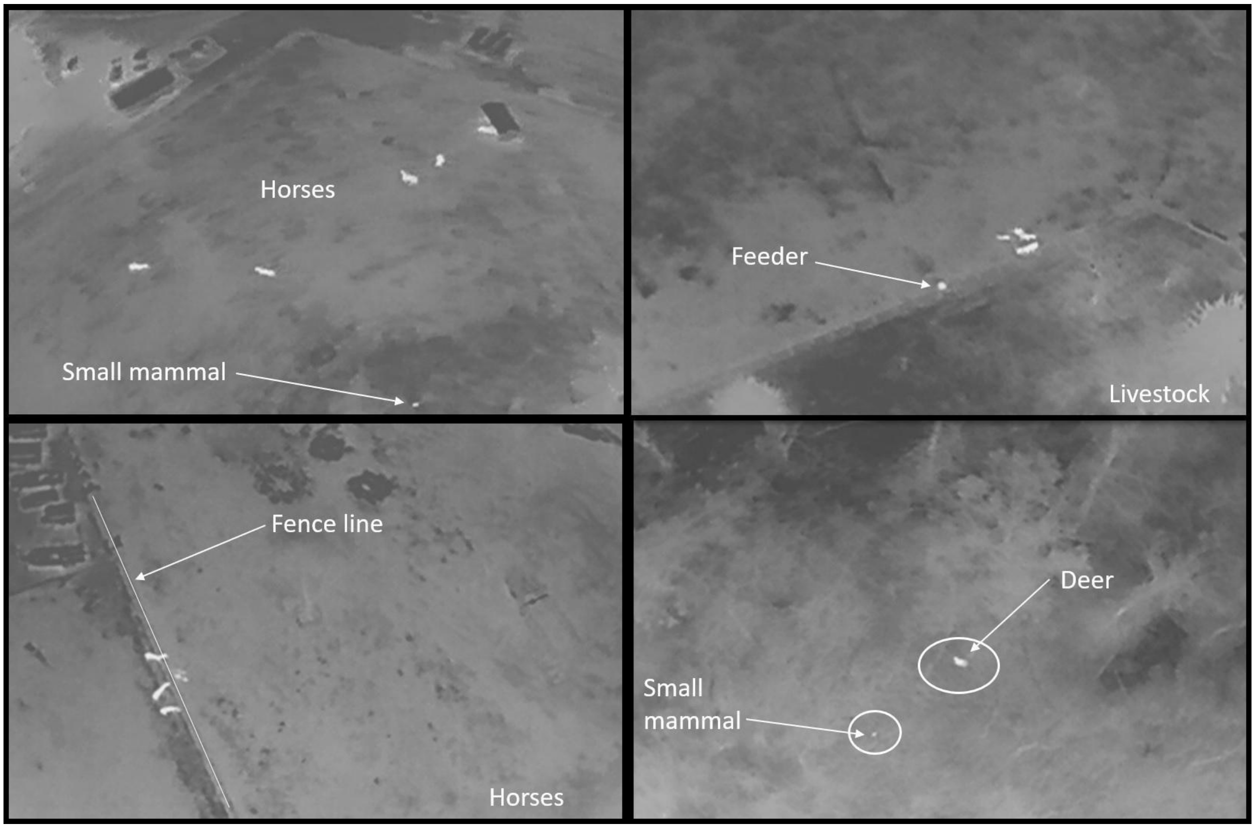


Figure 17: *Examples of how different objects and animal species have unique thermal signatures that are utilized for species identification during drone surveys.*

Figure 18: *Examples of the heat signatures of horses, goats, and cattle observed during drone surveys.*

Project Challenges

Thick evergreen canopies made for poor visibility, especially in the more robust Eastern Red Cedar groves, likely providing cover for deer that went undetected. Autumn Olive trees retained most of their leaves and added sight limitations for the fall surveys. Although some of the deciduous trees, specifically oaks, may have retained their leaves in November, thermal penetration was not an issue. Site access and range presented challenges at some launch and landing areas. This issue was overcome with the assistance of the HMFC Community Liaison and other local community members that provided land access.

Other heat signatures observed included boulders, field springs, pockets of water, ponds, streams, manhole covers, streetlights, active chimneys, storm drain inlets, electric transformers (ground and pole mounted), cars, junk lots, livestock, raptors, waterfowl, and other mammals (***Figures 19 and 20)***.

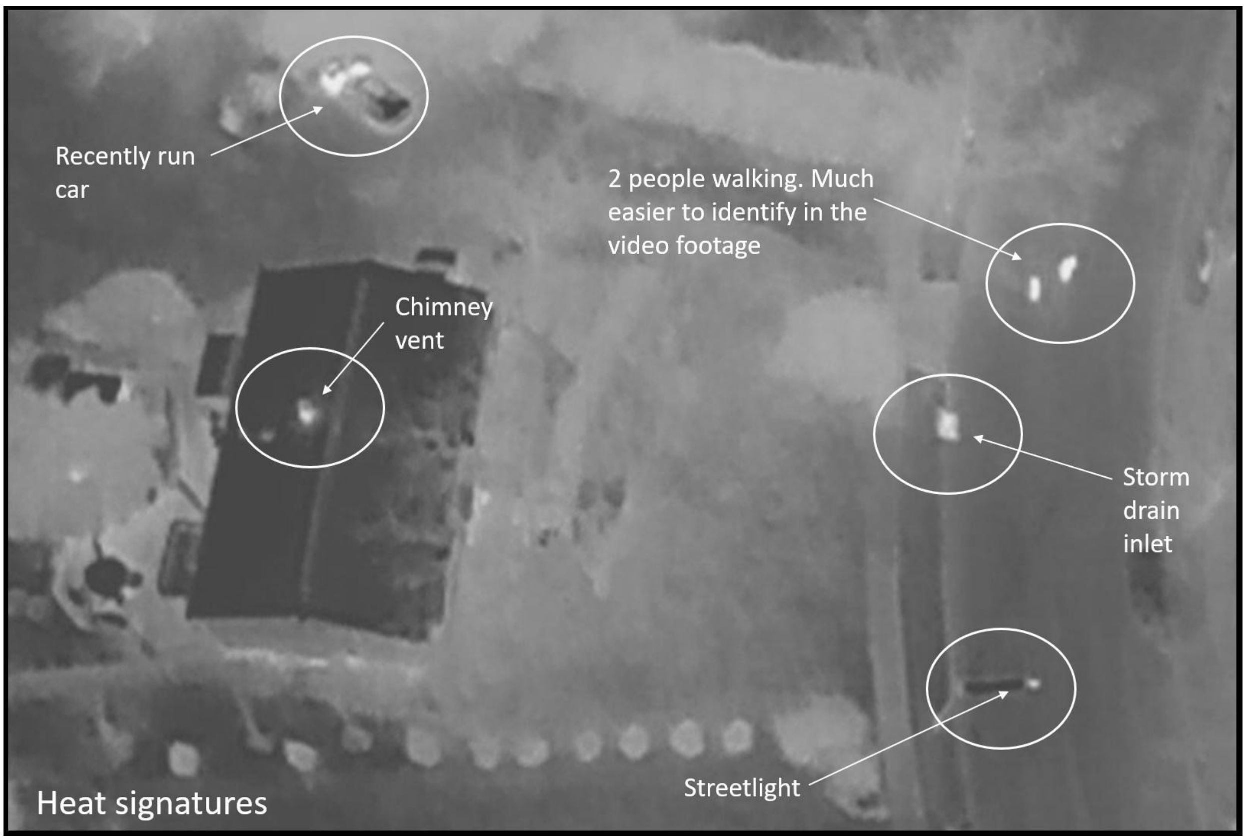


Figure 19: *Examples of the heat signatures of a car, chimney, streetlight, storm drain, and people that were observed during drone surveys. Drone operators must be able to distinguish between these types of objects and deer to prevent overcounting.*

Figure 20: *Examples of heat signatures that a drone operator reviews while determining different animal species and objects. This graphic includes a car, manhole, storm drain, covered inground pool, and white-tailed deer.*

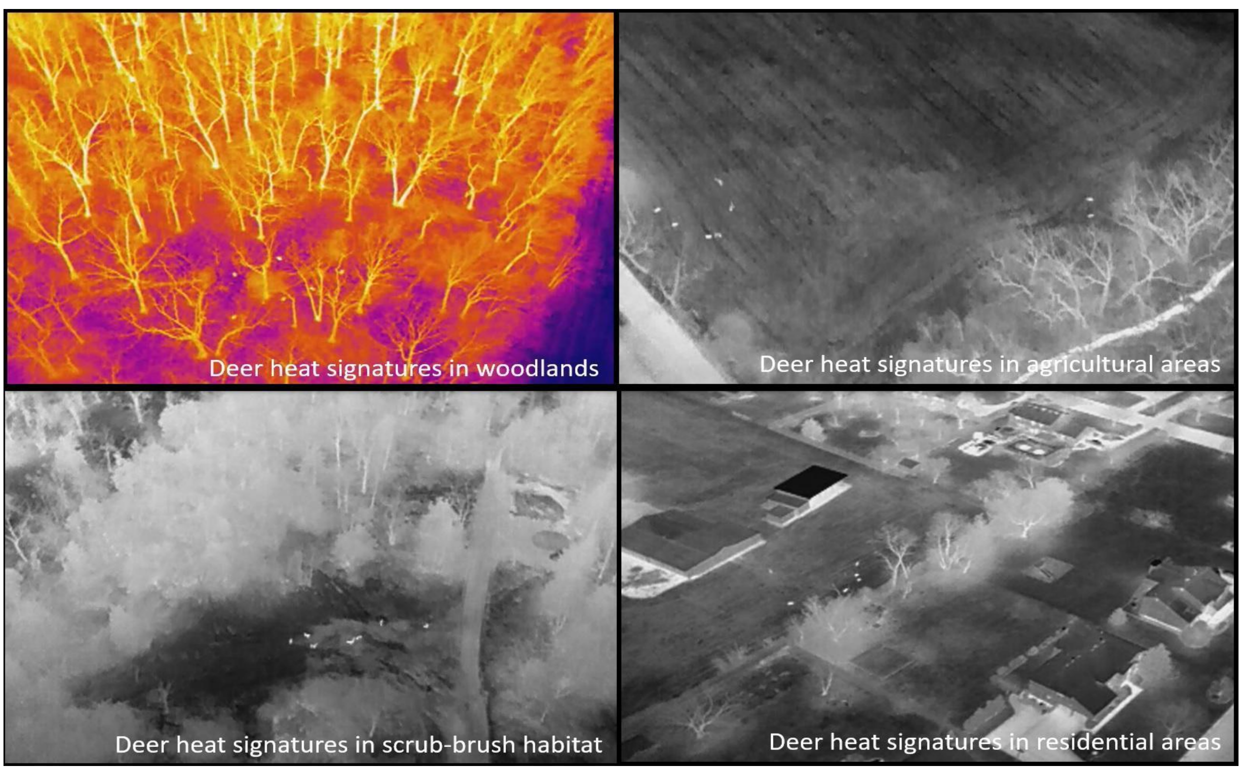


Figure 21: *Examples of deer heat signatures observed in different landscapes, including woodlands, agricultural fields, scrub-brush habitats, and residential neighborhoods.*

HMFC Deer Fence Exclosure

A fence was installed around 85 acres of forest in 2015 to protect the forest ecosystem from excessive deer browse which facilitates the spread of invasive plant species that threaten native herbaceous plants and tree seedlings. Since deer can jump over fences less than 8 feet tall, the fence is 8-foot high woven wire with two single strands of wire above to extend the overall height to 10 feet. This fence protects the 65-acre Mettler's Woods old growth forest that includes trees over 250 years old. Additionally, the fence protects many long-term research plots that study changes in the forest vegetation over time, including half of the Buell-Small Succession Study Fields.

A management challenge with a fence surrounding a mature forest is that trees periodically fall on, and damage, the fence due to old age, high winds, and storm events. Gaps that are created allow temporary access points where deer can move in and out of the exclosure until repairs can be completed. Deer have been observed inside the fence during every survey. Fence repairs are on-going and additional proactive forestry management techniques have been implemented to decrease future damage.

Habitat Classification

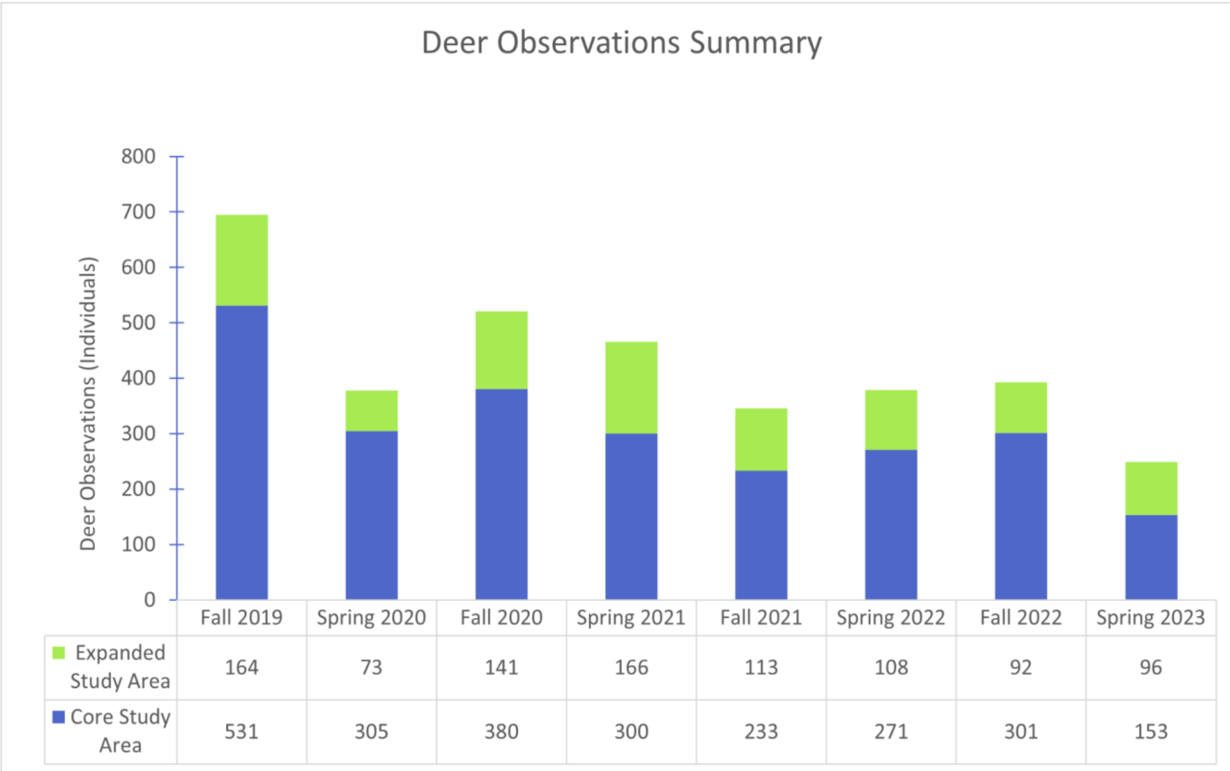
To understand habitat utilization of the deer population over time, the 2015 Land Use and Land Cover (LU and LC) classification of New Jersey were used to summarize deer observations by habitat type. This data comes directly from the New Jersey Department of Environmental Protection (NJDEP) Bureau of Geographical Information System (GIS). The LU and LC categories relevant to this study include agriculture, barren land, forest, wetland, urban, and water. Notably, the urban classification includes residential areas, major roads, cemeteries, and recreational lands like Colonial Park and Spooky Brook Golf Course.

Figure 22: *Land use and land cover classification for the Core Study Area. Source - New Jersey Department of Environmental Protection GIS data classification scheme derived from 2015 imagery.*

Results

The greatest number of deer observed throughout the Full Study Area occurred during the Fall 2019 drone survey. Results included 695 individual deer, of which 76.4% were located within the Core Study Area. We observed the lowest deer count during the Spring 2023 survey. The total deer count for that survey was 249 individuals, of which 61.5% were located within the Core Study Area (**Figure 23**).

The mean proportions of observations from Core Study Area and Expanded Study Area are 71.4% and 28.6% respectively. The largest ratio [4.18] of observations from Core to Expanded Study Areas occurred during the Spring 2020 survey event. The smallest ratio [1.59] of observations from Core to Expanded Study Areas occurred during the Spring 2023 survey event.



	Fall 2019	Spring 2020	Fall 2020	Spring 2021	Fall 2021	Spring 2022	Fall 2022	Spring 2023
Expanded Study Area	164	73	141	166	113	108	92	96
Core Study Area	531	305	380	300	233	271	301	153

Figure 23: *Bar graph showing individual deer counted in the Core and Expanded Study Areas between the Fall of 2019 and Spring of 2023 drone surveys.*

The greatest number of deer observed at one time were located within the Core Study Area during the Spring 2020 drone survey, and the greatest number of deer observed at one time in the Expanded Study Area occurred during the Spring 2023 survey.

The greatest concentration of deer occurred during the Fall 2019 survey, which yielded a density of 133 deer per square mile throughout the Full Study Area. The drone survey with the lowest concentration of deer took place in the Spring of 2023 and revealed 37 deer per square mile throughout the Full Study Area (**Figure 24**). Heat maps were used to demonstrate the changing concentrations of deer over time and space between the fall 2019 and spring 2023 drone surveys. Darker red represents more dense concentrations of whited-tailed deer observed during surveys (**Figure 25**).

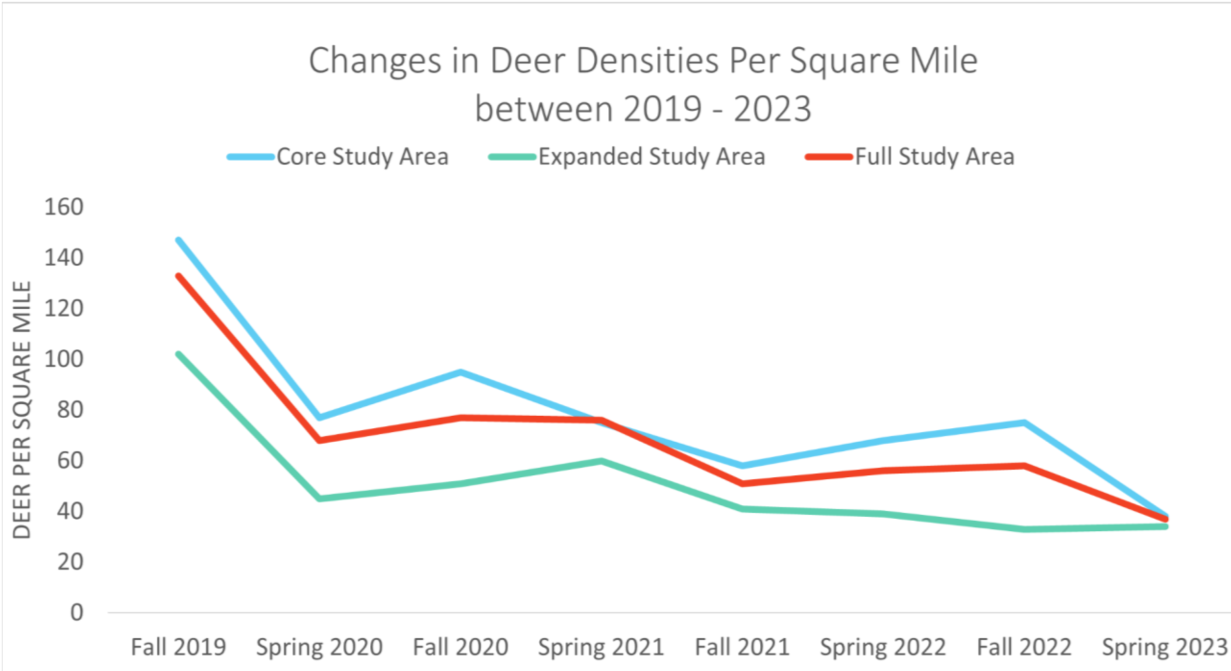


Figure 24: *Changes in deer density per square mile estimates within the Core, Expanded, and Full Study Areas between the fall of 2019 and the spring of 2023.*

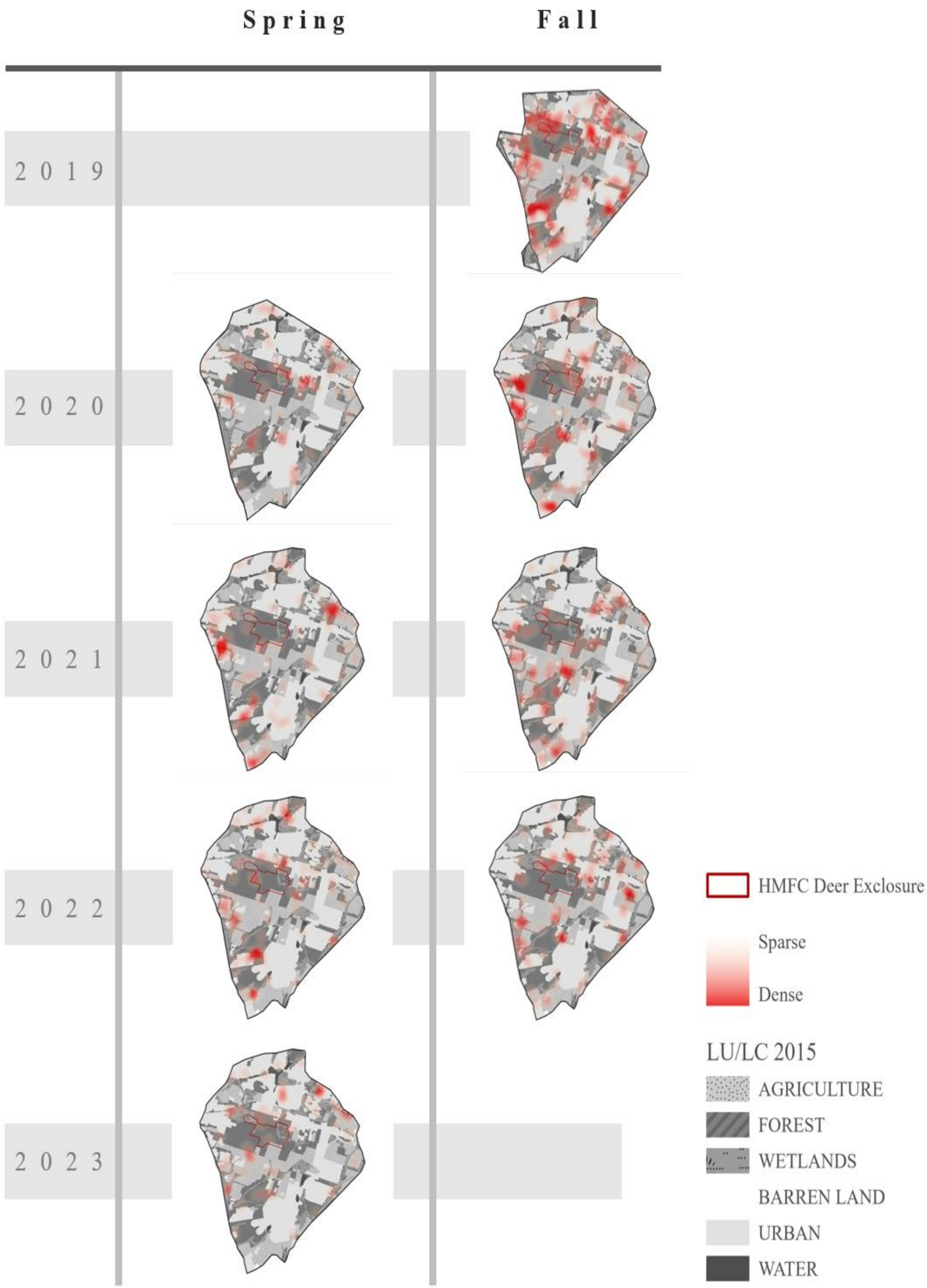
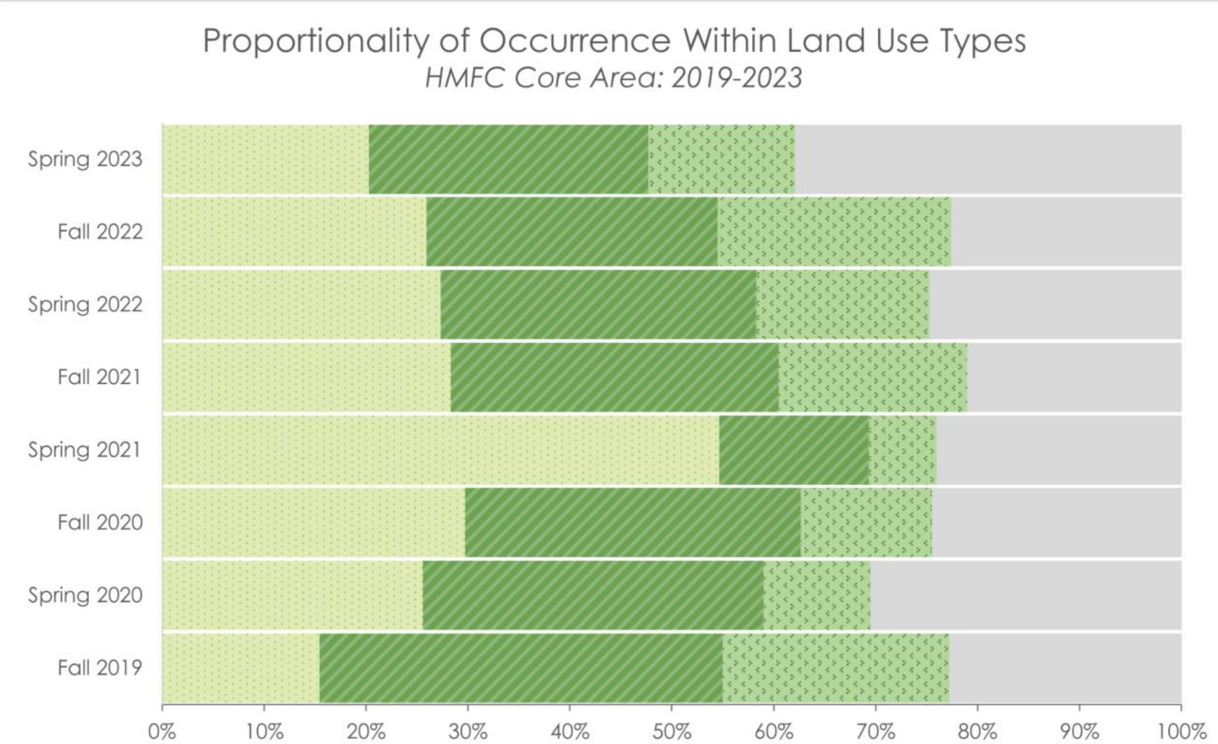


Figure 25: *Heat maps demonstrating the changing concentrations of deer over time and space between the fall 2019 and spring 2023 drone surveys. Darker red represents more dense concentrations of whited-tailed deer observed during surveys.*

The most prevalent land types throughout the Core Study Area were agriculture, forest, and urban land use and land cover classifications, and deer utilized these the most throughout all survey events. The mean percent composition of deer observations was 30.0%, 28.4%, and 26.0% in Forest, Agriculture, and urban land types, respectively. The highest proportion of deer observations (54.7%) within a land type occurred within the Agricultural Land Use and Land Cover during the Spring 2021 drone survey (**Figure 26**).



	Fall 2019	Spring 2020	Fall 2020	Spring 2021	Fall 2021	Spring 2022	Fall 2022	Spring 2023
Agriculture	15.44	25.57	29.74	54.67	28.33	27.31	25.91	20.26
Barren	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Forest	39.55	33.44	32.89	14.67	32.19	31.00	28.57	27.45
Wetland	22.22	10.49	12.89	6.67	18.45	16.97	22.92	14.38
Urban	22.79	30.49	24.47	24.00	21.03	24.72	22.59	37.91

Figure 26: *This graphic illustrates the proportionality of the occurrence of white-tailed deer observed within the different land use types (forest, agricultural, and urban). Land use types were identified from the 2015 New Jersey Department of Environmental Protection GIS data on Land Use and Land Cover.*

Discussion and Conclusions

Wildlife management involves striving to achieve a positive balance in human-wildlife interactions. Many factors must be considered, including ensuring healthy wildlife populations, benefits associated with wildlife, damage impacts, and safety concerns. This is especially challenging in the most densely populated state in the US, where development has created fragmented landscapes. People and wildlife live in close proximity and interact regularly (Paulin et al. 2022).

White-tailed deer numbers have increased in New Jersey over the past several decades, which has presented many challenges for management. Although densities of 10 deer per square mile are recommended to maintain benefits for social, economic, and ecosystem integrity (Kelly, 2019), numbers recently observed throughout the state have ranged as high as 60 to 239 deer per square mile (NJFB/SG 2019).

Additionally, in a 2022 Rutgers University case study, farmers overwhelmingly reported that there were too many deer, causing significant damage to farmed properties and surrounding landscapes throughout the state (Paulin et al. 2022). Nearly all case study farmers reported that adjacent neighborhoods, woodlands, and open spaces are serving as refuge areas for deer that feed in the farm fields at night, causing extensive crop damage. For developed and residential areas where hunting is not allowed or practical, or where hunting alone cannot remove enough deer, farmers encourage townships to apply for a New Jersey Department of Environmental Protection Fish and Wildlife, Community Based Deer Management Program permit https://www.nj.gov/dep/fgw/cbdmp.htm. This permit allows for additional lethal management options and the removal of deer outside of regulated hunting seasons. Townships are also encouraged to look for opportunities to donate the venison to food banks to help those in need in their community.

Public and private lands, such as the Hutcheson Memorial Forest Center, prior to the initiation of the deer management program, act as refuges for deer causing crop and landscape damage. Landowners and managers of these types of lands should allow access to management activities or develop wildlife management plans to reduce negative impacts on neighboring farms, forests, and residential areas and decrease deer-vehicle collisions. Some existing programs for managing deer on public lands, including doe-focused bowhunting programs and allowing depredation permits, have reported positive results (Huntington et al. 2020, Paulin et al. 2022, Paulin 2023).

Although management objectives for deer in suburban areas are commonly less than 20 deer per square mile (Drake et al. 2002, Waller and Alverson 1997), to reduce threats from extensive deer browse to biodiversity, deer densities may need to be less than 10 deer per square mile (Kelly 2019). Further, situations are site-specific; no density estimate recommendation translates to all areas, and managers should recognize the importance of reducing negative impacts and not just an arbitrary reduction in deer numbers (Boulanger et al. 2014). Depending on the situation, even a small number of deer can cause intolerable levels of damage.

Management activities to protect the HMFC from deer damage began in 2015, with the construction of a fence around 85 acres, followed by the initiation of a community-based, doe-focused, volunteer bowhunting program in 2019. A monitoring program involving drone surveys was implemented prior to the start of the management hunt in November 2019. Pre-hunt surveys revealed that density estimates in the area were nearly 150 deer per square mile (NJAES/HMFC/SG 2020) and greatly exceeded the recommended levels of 10 deer per square mile (Kelly 2019).

Between the fall of 2019 and spring of 2023, the management and monitoring collaboration involving the New Jersey Agricultural Experiment Station, Rutgers Cooperative Extension, Hutcheson Memorial Forest Center (HMFC), Steward Green, and the local community has shown success and observed drops in deer densities from nearly 150 deer per square mile to approximately 40 deer per square mile within the Core Study Area. The initiation of the management program and increased hunter effort and presence on the properties, especially in 2020 – 2021 during the COVID-19 pandemic, have contributed greatly to the program's success in reducing deer numbers in the area (Paulin 2023).

The community-led deer management program at the HMFC has been a success. Since the program began and deer numbers have decreased, ecologists have observed native vegetation returning to the forest. The program can serve as a model for similar areas experiencing negative impacts from overabundant deer populations. Participants in the doe-focused deer management program have been very active on the HMFC properties during bowhunting seasons and harvested over 150 deer since the program began in 2019. Nearly 70% of the deer removed to protect native vegetation and decrease damage in the surrounding areas were female, and 85% were antlerless. An additional benefit of the program has been the donation of over 13,000 servings of protein to the Franklin Foodbank to help those in need in the community.

An unknown number of deer were also harvested through hunting on public and private lands in the area and through the implementation of farmer depredation permits to remove deer causing agricultural damage. In landscapes like the study area that included a mixture of forested, agricultural, and residential housing, deer have exhibited seasonal changes in activities, including expansions of ranges during and following hunting seasons (Rhoads et al. 2010). Temporary changes in deer ranges may have also contributed to lower numbers. Additionally, November is the peak of the breeding season when male deer will be more active and extend their range in pursuit of females.

Another issue to keep in mind is that in the late summer and early fall of 2021, the New Jersey Department of Environmental Protection, Fish and Wildlife confirmed Epizootic Hemorrhagic Disease (EHD) in parts of the state (NJDEP, FW 2021). Although no cases were confirmed in Somerset County and the immediate area around the HMFC, it is possible that this may have been an additional contributing factor to lower deer numbers observed during surveys in late 2021 and early 2022. Anecdotally, several participants of the management hunt reported the smell of rotting carcasses while walking through the forest, as well as encountering some deer with no apparent cause of death.

The deer drone surveys at the HMFC and surrounding areas are a critical element of an overall program that is planned to include long-term research, management, and educational components. The HMFC deer management program will serve as a community partnership and demonstration project for decision-makers and land managers. This program will allow for the study of changes over time in white-tailed deer densities and associated damage to forest ecosystems, agricultural crops, residential areas, and deer-vehicle collisions while implementing a doe-focused lethal deer management program utilizing bowhunters to mitigate deer damage.

-End of Report-

Glossary of Terms

Above Ground Level (AGL) – Height sUAV is above ground level

Aerial – Happening or operating in or from the air.

Calibrate – To correlate the readings of an instrument with those of a standard to check the instrument's accuracy; to adjust to take external factors into account or to allow comparison with other data (Lexico 2020).

Deciduous Trees – Tree species that lose their leaves at the end of their growing season (Biology Dictionary 2020).

Digital – Relating to, using, or storing data or information in the form of digital signals via computer technology (Lexico 2020).

Ecotone – A defined edge, border or line in habitat, typically where a forest meets a meadow. Many species of fauna use an ecotone as a place to forage, as one side (forest) provides greater protection.

Egress – A way out (Lexico 2020).

Esri Data Collector – A mobile data collection app made to capture and edit geographic data accurately and easily from the field and return it to the office (Esri 2020).

Evergreen Trees – Trees that retain their green leaves/needles throughout the year (Lexico 2020).

Federal Aviation Administration (FAA) – The agency of the US Department of Transportation responsible for the regulation and oversight of civil aviation within the US, as well as operation and development of the National Airspace System. Its primary mission is to ensure safety of civil aviation (SKYbrary 2016).

Fixed Wing – An aircraft designed similar to that of an airplane, allowing for a larger flight range, yet requiring a larger takeoff/landing zone (DroneDeploy 2017).

Flora – The plants of a particular region, habitat, or geological period (Lexico 2020).

Forest Ecology – The study of all aspects of the ecology of wooded areas, including rainforest, deciduous and evergreen, temperate and boreal forest. It includes the community ecology of the trees and other plant and non-plant species, as well as ecosystem processes and conservation. (Nature.com 2020).

Fauna – Also known as "wildlife"; the animals of a particular region, habitat, or geological period (Lexico 2020).

Forest Regeneration – The act of renewing tree cover by establishing young trees naturally or artificially (Watson et al. n.d.).

Forest Understory – Also known as "undergrowth" or "underbrush"; refers to the underlying layer of vegetation (saplings, shrubs, and other plant life) growing beneath a forest's canopy.

Forward-Looking Infrared (FLIR) – Technology that detects thermal energy, or variances in heat.

Geo-reference – To take an ordinary image, drawing, schematic, etc. and give it real-world coordinates (GISGeography 2017).

Heat Signature – A visual representation of the unique exterior temperature of an object or living thing.

Image Overlap – The amount by which one photograph includes the area covered by another photograph and is typically expressed as a percentage (Natural Resources Canada 2016).

Infrared – Electromagnetic radiation having a wavelength just greater than that of the red end of the visible light spectrum but less than that of microwaves. Infrared radiation wavelengths range from 800 nm to 1 mm and are emitted particularly by heated objects (Lexico 2020).

Ingress – A place or means of entrance or access (Lexico 2020).

Invasive Species – Any kind of living organism that is not native to an ecosystem and causes harm; can harm the environment, economy, or even human health; can grow and reproduce quickly, and spread aggressively, with potential to cause harm; does not necessarily come from another country (National Wildlife Federation n.d.).

Native – Descriptive of species naturally occurring in a particular region, ecosystem, or habitat without human introduction; native plants and wildlife have developed symbiotic relationships and therefore offer the most sustainable habitat (National Wildlife Federation n.d.).

"Likely" Count – Includes deer counted in the data that have been confirmed, plus deer that are probable, but not confirmed. These numbers are considered probable yet have not been confirmed due to poor visibility or obstacles obstructing the line of vision.

Confirmed Count – Deer counted in the data that have been verified by an experienced professional/wildlife biologist based on shape, size, scale, movement, habit, etc. and has not already been counted.

Mission – A flight conducted for the purpose of collecting data. Multiple missions may be flown from the same launch/landing site if necessary.

Over-browsing – Eating vegetation so much that it becomes detrimental to the environment.

Photogrammetry – The use of photography in surveying and mapping to measure distances between objects (Lexico 2020).

Pilot in Command (PIC) – The person controlling the sUAV and ultimately responsible for the entire operation, cause and effect of the drone as per Part 107 of FAA rules and regulations

Population Density – Represents the number of species within a specific measured area.

Repeatability – The capability of performing the process of data collection in repetition, increasing efficiency and accuracy of the study.

Sampling Areas – Sub-areas of study defined by counties, townships, city blocks, or other well-defined geographic sections of the population of which the survey is being conducted.

Site Reconnaissance – In regards to this study, a daytime survey to identify actual and potential hazards, to become familiar with the layout of the sampling site, and to identify launch/landing locations and access to said locations.

Species – a category of biological classification ranking immediately below the genus or subgenus, comprising related organisms or populations potentially capable of interbreeding

Strip Transects – A methodology that involves defining a strip of a certain width within the area of study, collecting data only within these constraints. The estimated densities are then extrapolated to the uncovered areas to gain a population estimate (Aars 2019).

Temporary Flight Restriction (TFR) – A type of Notice to Airmen (NOTAM) that defines an area restricted to air travel due to a hazardous condition, a special event, or a general warning for the entire FAA airspace (FAA n.d.).

Thermal – Relating to heat (Lexico 2020).

Ungulate – A hoofed mammal (Lexico 2020).

Unmanned Aerial System (UAS) – Or a small Unmanned Aerial System (sUAS) describes a remote-operated drone with a sensor attached.

Unmanned Aerial Vehicle (UAV) - Or a small Unmanned Aerial Vehicle (sUAV) refers directly to the drone.

Vertical Take-Off and Landing (VTOL) – Single or multiple rotor aircraft capable of taking off, hovering, and landing vertically, allowing for greater maneuverability

Visual Observer (VO) – The person responsible for maintaining situational awareness and visual line-of-sight, as well as for alerting the rest of the crew about potential hazards during sUAS operations (UAV Coach).

Mapping

All maps throughout this report were created by Steward Green™ unless otherwise stated, using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. For more information about Esri® software, please visit www.esri.com. All data included in this report was collected in the months of November and March beginning in the Fall of 2019 through the Spring of 2023 using thermal images obtained by sUAS. Data was initially recorded in the field using the Collector for ArcGIS data collection application, then FieldMaps when Collector was phased out by Esri. Images were later reviewed to ensure data accuracy. All maps were created using the Web Mercator coordinate system. The following is a citation of map layers used that were not created by Steward Green™: State, Local and Nonprofit Open Space of New Jersey https://njogis-newjersey.opendata.arcgis.com/datasets/4a1f9d3075a04cd792a14f78b9697df3_65

Sources: NJDEP's Geographic Information System (GIS), Esri, DigitalGlobe, GeoEye, i-cubed, Esri ArcGIS World Imagery Base Layer, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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Steward Green LLC has consulted clients for many years in thermal data collection, conservation, wildlife habitat regeneration, bioretention, and ecosystem services development. The lead consultant has been performing successful heat signature work since 2001, starting with a helicopter and then airplane-mounted Forward-Looking Infrared (FLIR). In 2013, Steward Green started using sUAS with thermal infrared sensors as the technology became more reliable, and the data collected was of better quality, more affordable, and safer than traditional methods.

This project was funded through a partnership of the Rutgers University School of Environmental and Biological Sciences (SEBS) Executive Dean's Office, New Jersey State Agricultural Experiment Station (NJAES) Rutgers Cooperative Extension, and the Hutcheson Memorial Forest Center. Steward Green conducted all deer density surveys. The New Jersey Department of Environmental Protection Fish and Wildlife, New Jersey Farm Bureau, Franklin Township Deer Management Program, and local community members were also consulted on various aspects of the project and made valuable contributions, including facilitating access to private lands.

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