Rutgers White-Tailed Deer (Odocoileus virginianus) Population Density Survey using sUAS Infrared: Hutcheson Memorial Forest Center and surrounding landscapes of Franklin and Hillsborough Townships *-November 2019 and March 2020*

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This report describes the white-tailed deer (*Odocoileus virginianus*) density of the Rutgers University Hutcheson Memorial Forest Center (HMFC) and surrounding areas of Franklin and Hillsborough Townships before and after the initiation of a deer management program in 2019 at the HMFC. 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. This area is also a known hotspot for white-tailed deer-vehicle collisions and deer-related crop damage in Franklin Township.

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 and data analysis. The New Jersey Division of 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 those listed below for contributions to the project.

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Executive Summary

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 that controls 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. The economic impacts from unwanted deer-human interactions in New Jersey, including damage to vehicles, agricultural crops, and commercial and residential landscaping, were conservatively estimated to be $69,000,000 annually (Drake et al. 2005). Additionally, damage by white-tailed deer has been estimated at approximately $2 Billion in the United States annually (Boulander et al. 2014).

Although management objectives for deer in suburban areas are commonly less than 20 deer/square mile, to reduce threats from extensive deer browse to biodiversity, deer densities may need to be less than 10 deer/square mile. 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 (Boulander 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.

All of New Jersey's forests are 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. In other areas, deer densities of less than 15 deer/square mile have been recommended to reduce negative impacts from deer browsing on woody and herbaceous plants (Waller and Alverson 1997).

The Hutcheson Memorial Forest Center (HMFC) located in Franklin Township, New Jersey, comprises several parcels of land totaling over 500 acres. ***See 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, 200 species of birds (Hutcheson Memorial Forest Center, 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 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. 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).

In November 2019 and March 2020, drone surveys were conducted to provide snapshots in time of the white-tailed deer density for the Rutgers University Hutcheson Memorial Forest Center and surrounding areas of Franklin and Hillsborough Townships. For the purpose of this study, we refer to two distinct areas (East & West): HMFC and Franklin Township (East) and Hillsborough Township (West), utilizing the Delaware and Raritan Canal as the dividing line. We used this dividing line because deer are less likely to cross the canal and/or Millstone River under normal conditions, limiting their typical range. Surveys were conducted before and after the initiation of a doe-focused deer management program to remove deer from the property and reduce deer-related herbivory threatening the forest ecosystem.

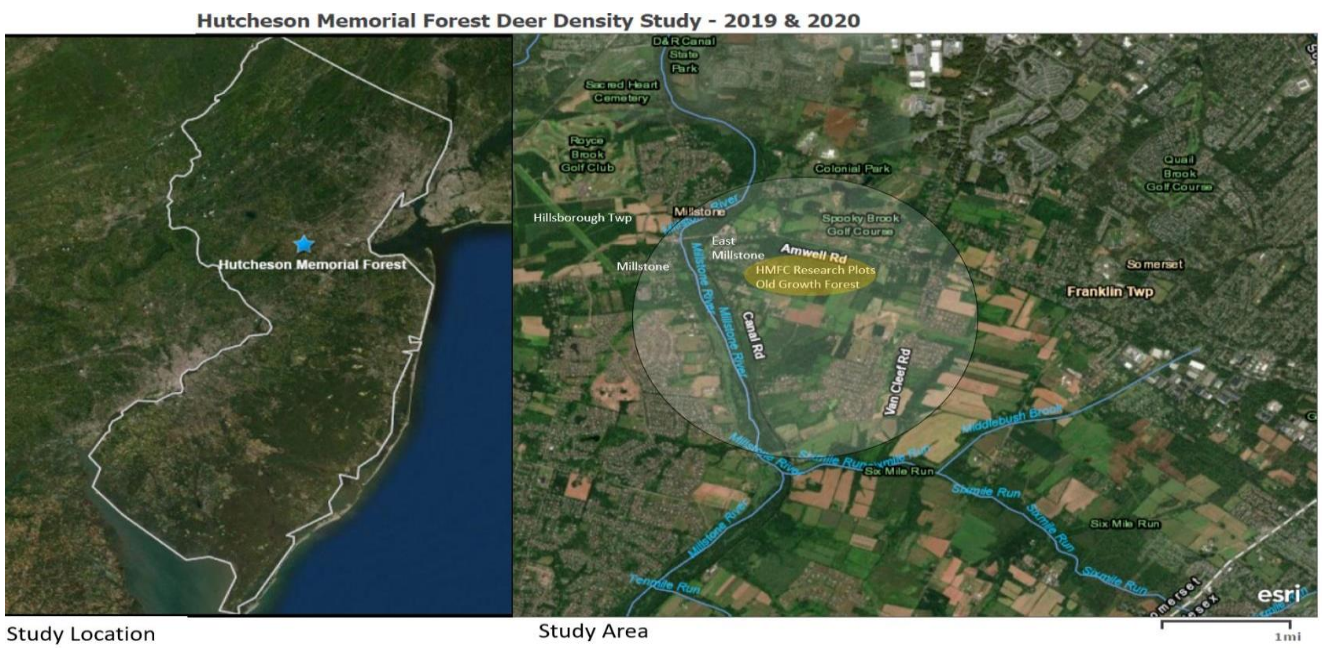

***Figure 1**. Hutcheson Memorial Forest Center deer population density study location map*

Immediately prior to hunting in November 2019 approximately 5.20 square miles were surveyed in total: 3.62 square miles for HMFC and Franklin Township (East) area and 1.58 square miles for Hillsborough Township (West). Confirmed deer density was estimated at 147 deer per mi^2 for HMFC and Franklin Township (East). For nearby Hillsborough Township, the confirmed deer density was estimated at 104 deer per mi^2. ***See Table 1.*** In March 2020, approximately three weeks following the conclusion of hunting activities, roughly 5.57 square miles were surveyed in total: 3.96 square miles for HMFC and Franklin Township (East) area and 1.61 square miles for Hillsborough Township (West). Confirmed deer density was estimated at 77 deer per mi^2 for HMFC and surrounding areas of Franklin Township. In Hillsborough Township the confirmed deer density was estimated at 45 deer per mi^2. It is likely that more deer were present and obscured by areas of thick vegetation. Additionally, only images confirmed to be deer by the research team during the survey, followed by analysis of the images in the lab were counted. These methods are more accurate and provide conservative estimates. Differences between the November 2019 and March 2020 surveys may have been the result of several contributing factors. Participants in the deer management program were regularly active on the HMFC properties and harvested 37 deer, over 80% of which were female, between November 23, 2019 and February 15, 2020. An unknown number of deer were also harvested through hunting on private lands in the area and through the implementation of farmer depredation permits. Temporary changes in deer ranges may also have been a contributing factor. In landscapes similar to the study area that included a mixture of forested, agricultural and residential housing, where habitat patches are connected, deer have exhibited seasonal changes in activities including expansions of ranges during and following hunting seasons (Rhoads et al. 2010). November is also the peak of the breeding season when male deer will extend their range. An additional consideration for deer management is that adult does can produce two and sometimes three fawns per year under ideal conditions (Boulander et al. 2014).

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 crops, residential areas, and deer-vehicle collisions while implementing a doe-focused lethal deer management program utilizing bowhunters to mitigate deer damage. Helping those in need is also a key component of the program and in 2020 participants donated over 500 pounds of venison to the Franklin Food Bank.

Table 1. *Hutcheson Memorial Forest White-tailed deer population density*

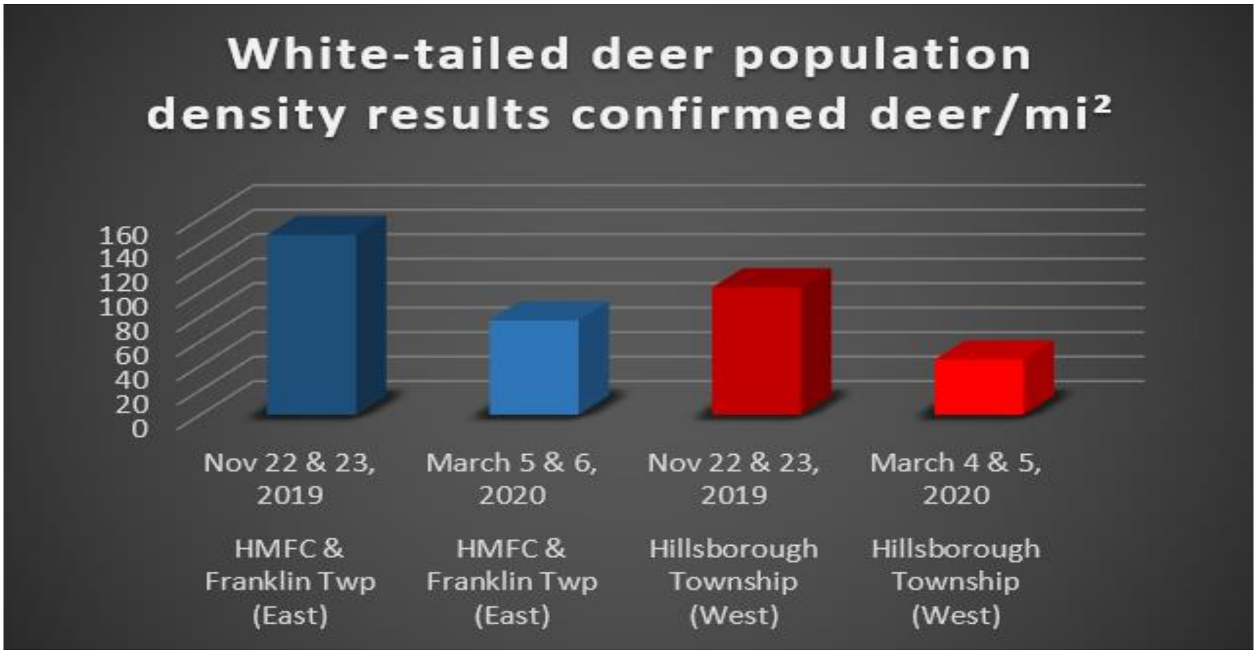

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TABLE OF CONTENTS

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). 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 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. The economic impacts from unwanted deer-human interactions in New Jersey, including damage to vehicles, agricultural crops, and commercial and residential landscaping, were conservatively estimated to be $69,000,000 annually (Drake et al. 2005). Additionally, damage by white-tailed deer has been estimated at approximately $2 Billion in the United States annually (Boulander et al. 2014). Although management objectives for deer in suburban areas are commonly less than 20 deer/square mile, to reduce threats from extensive deer browse to biodiversity deer densities may need to be less than 10 deer/square mile. 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 and arbitrary reduction in deer numbers (Boulander 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 (Boulander et al. 2014).

Agricultural Damage

Deer damage is described by NJ Farm Bureau as an epidemic and was voted as the #1 issue among farmers at their 2018 and 2019 Annual Meetings. Effectively addressing damage and deer-refuges is critical to industry sustainability. Excessive damage has led to field abandonment and changes in crop selection negatively impacting 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 a parcel of *tillable ground* 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). Agricultural damage has been reported throughout the entire study area in this report. A variety of non-lethal and lethal management techniques have consistently been implemented in all the sampled areas but have not succeeded in reducing local deer populations to achieve economic viability for farmers.

Figure 2. *Photo- Geoff Slifer: Exclosure demonstrating deer damage to agricultural crops.*

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. In other areas, deer densities of less than 15/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 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). Without proper understory, new seedlings never become mature trees, thus the forest is lost through *attrition* and the overall structure and composition of vegetation changes as non-native, invasive plant species invade (Alverson et al. 1988, Cote et al. 2004, Horsely et al. 2003). Without *biodiversity* in the woodlands, other species suffer from direct and indirect results of deer overabundance (Alverson et al. 1988). *Insectivorous* birds, that also eat ticks, nesting on or near the ground such as ovenbirds (*Seiurus aurocapilla)* and other *neo-tropical migratory birds* have less habitat, which can contribute to population declines. When understory habitat is disappearing, biodiversity decreases across the board, negatively affecting other species of flora and *fauna* (Horsley et al. 2003). Insects lose feeding species and pollinators lose nectar sources and host plants. When more of the understory is eaten by deer, root systems that hold soil in place are decreased causing *erosion* and *sedimentation* to increase. Failure to acknowledge such ecological interactions and allowing such dense populations of deer works directly against preservation of natural diversity (Alverson et al. 1988). Native planting programs, *reforestation* and other conservation programs are also very difficult to implement with high deer densities.

Figure 3. *Photo - Scarlett Simpson: HMFC research plots before and after removal of invasive plants.*

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 4*. Photo- Joe Paulin: HMFC research plots before and after removal of invasive plants.*

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). The number of claims in NJ is high yet many of the minor accidents do not even get reported.

Figure 5. *Photo - Joe Paulin: Deer struck by a vehicle across from the HMFC on Amwell Road in Franklin Township.*

From October to December of 2016, American Automobile Association reported 4,463 reported deer-vehicle collisions in New Jersey in just a 3 month span. In 2018, Somerset county ranked third highest in state with 364 reported deer crashes (Flammia 2018). Between July 1, 2017 and June 30, 2018, over 26,000 deer collisions were recorded statewide according to insurance company State Farm’s 2018 Deer Collision Statistics report. Somerset County remains one of the highest vehicular accident counties related to deer in New Jersey, ranked No. 11 in the state with 128 incidents claimed in 2017 (Sherman 2018). Hillsborough Township, located in Somerset County, New Jersey, ranked No. 1 with the most reported vehicular accidents related to deer in 2017, making 316 insurance claims (Sherman 2018).

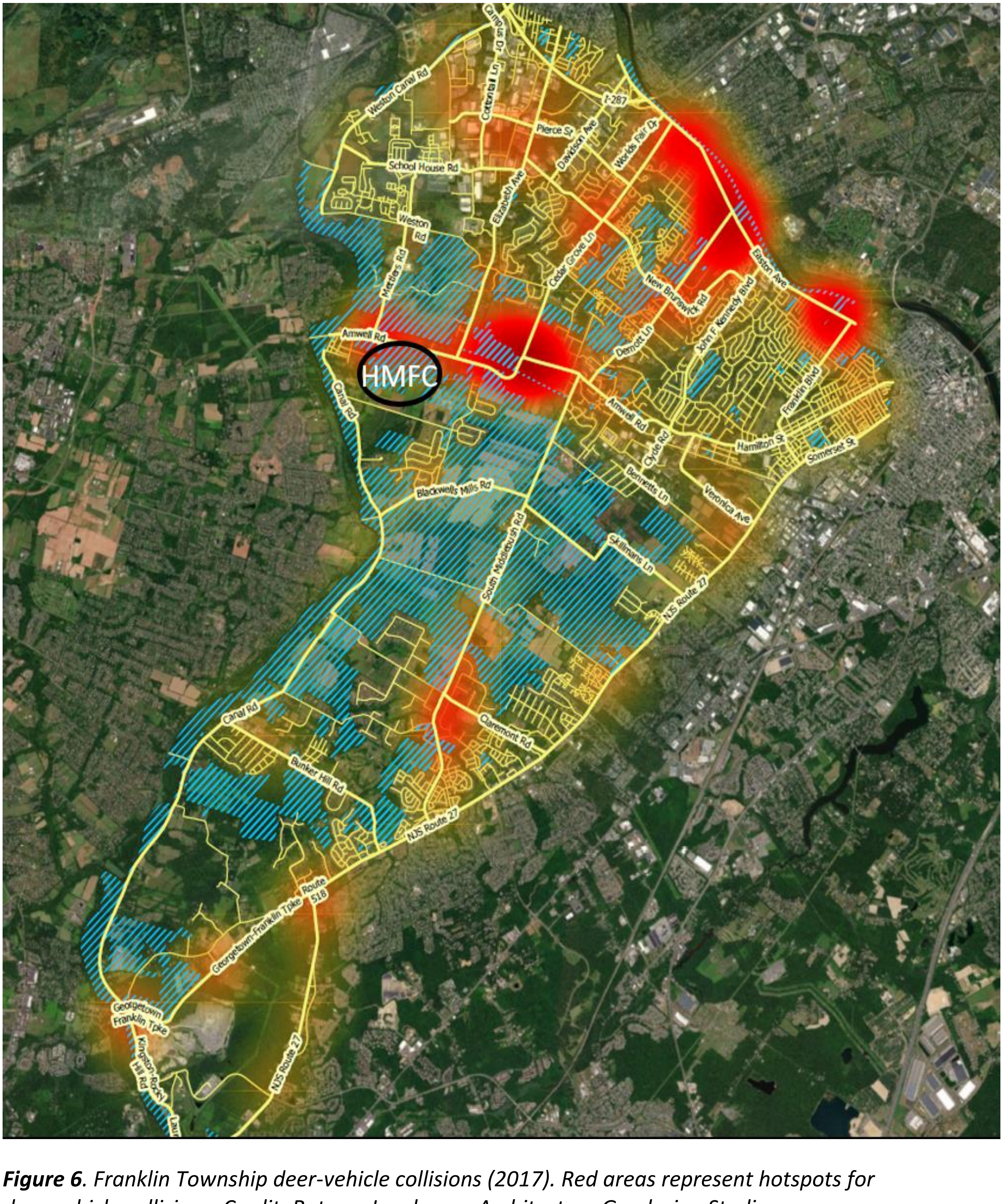


***Figure 6**. Franklin Township deer-vehicle collisions (2017). Red areas represent hotspots for deer-vehicle collisions. Credit: Rutgers Landscape Architecture Geodesign Studio*

Disease Concerns

Lyme disease is a severe problem 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). **See Figure 7**. 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, thus the Lyme disease epidemic. Note that deer are among many mammals that carry ticks but are not the primary vector.

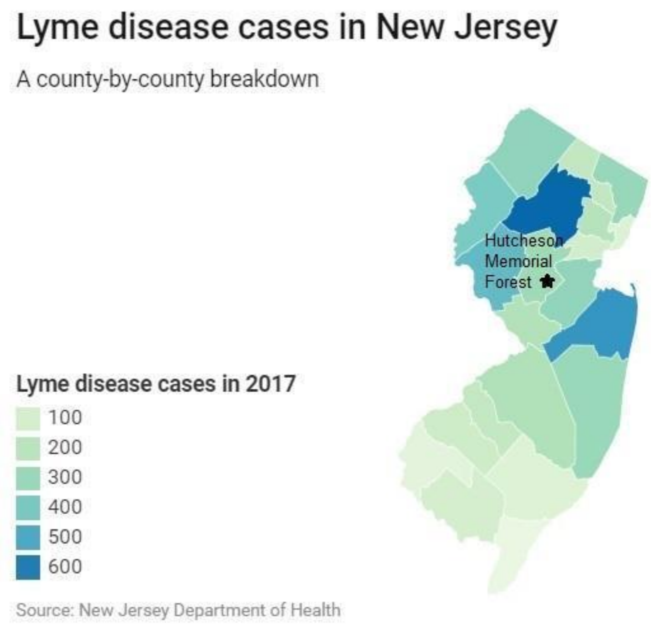


***Figure 7**. Lyme disease cases in New Jersey*

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.

Excessive crop damage has led to field abandonment and changes in crop selection negatively impacting farmers' livelihoods. Forty three percent of respondents from the 1998 Rutgers University "*How are white-tailed deer affecting agriculture in New Jersey?*" survey indicated the presence of a 100 acre or greater parcel of land serving as a deer refuge within one mile of the area of their most severe crop losses. Additionally, 50% of respondents with intolerable losses indicated a deer refuge within a mile of their most severely affected fields. Most deer refuges were reported under private ownership, with publicly owned parcels causing problems in several counties throughout the state (Fritzell, 1998).

Today, policymakers with 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. For this reason, and where possible, several municipalities throughout the state have initiated programs to open potential refuges to regulated hunting in an attempt to decrease deer densities, associated damage and address safety concerns.

Survey Objective
To provide estimates of white-tailed deer population density for the Rutgers University Hutcheson Memorial Forest Center and surrounding areas of Franklin and Hillsborough Townships before and after the implementation of a deer management program (2019-2020).

***Infrared* Accuracy**
Steward Green LLC (SG) provided Rutgers University 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/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
The area surveyed included the Rutgers University Hutcheson Memorial Forest Center (HMFC) and surrounding areas of Franklin and Hillsborough Townships consisting of residential neighborhoods, forested, agricultural lands and open spaces (e.g., part of Spooky Brook Golf Course, Colonial Park, Delaware and Raritan Canal and the Millstone River. **See *Figure 8*.** Approximately 5.20 square miles (3,328 acres) were included in the November 2019 survey. The March 2020 survey comprised approximately 5.57 square miles (3,566 acres). The additional acreage in March 2020 came from the addition of the southern section of Colonial Park. 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 areas.

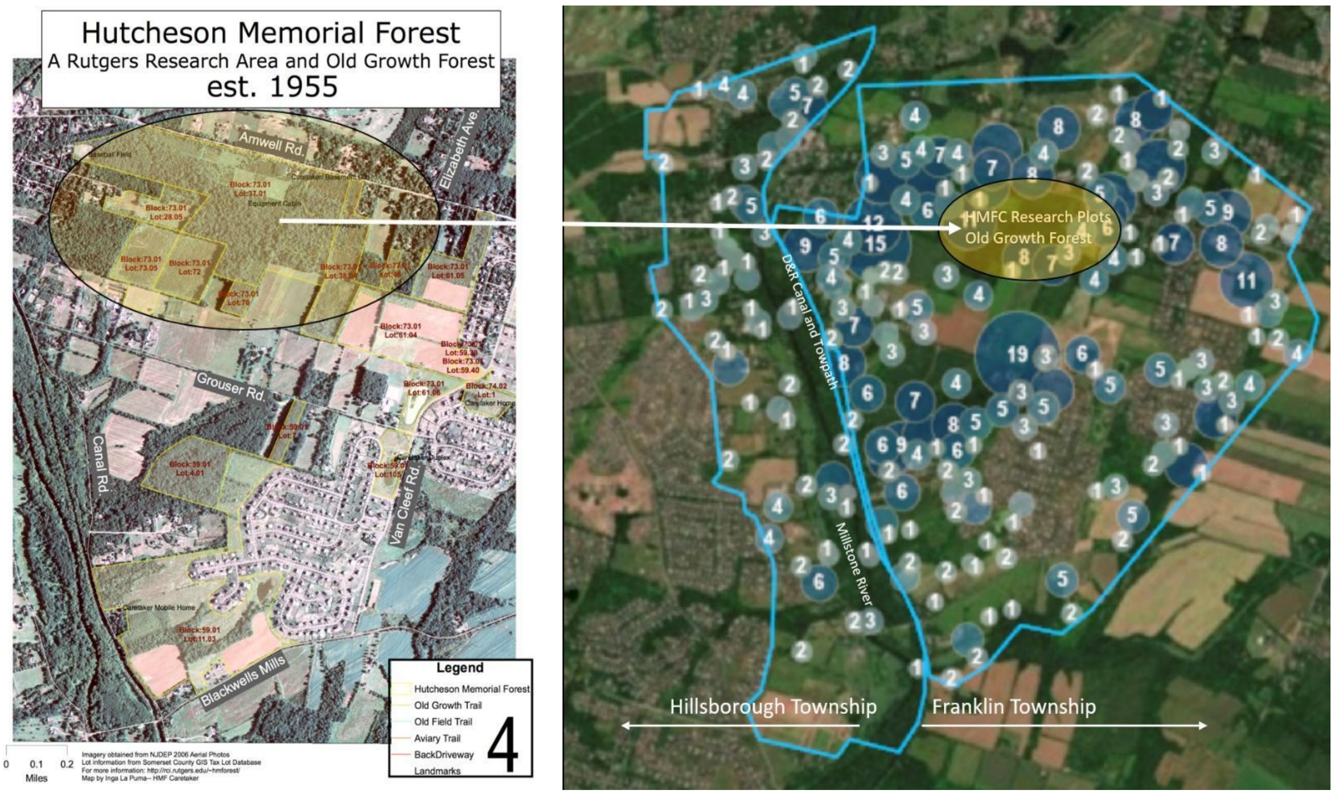


***Figure 8**. HMFC Research Area, Old Forest Growth and example of data collection in Franklin and Hillsborough Townships, November 2019. Circles with numbers represent the number of individual deer that were counted in that area.*

Methodology

Preparation

Pre-survey site reconnaissance included Federal Aviation Administration (FAA) mandatory 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 in November 2019, making the process much easier to confirm in March 2020. The NJAES/RCE and HMFC teams familiar with the area participated in the surveys and facilitated access to launch sites on private lands. ***See Figure 10.***

Pilots were approved to perform UAS operations based on certifications with the *Federal Aviation Administration* (FAA) and standard procedures. The *missions* 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 Hillsborough and Franklin Township Police, Central Jersey Regional Airport, Somerset County Parks Commission, and neighbors in or surrounding the study area.

The study area was split into two sections, HMFC and surrounding areas of Franklin Township (east) and Hillsborough Township (west). ***See Figure 8***. The two sections were separated by the Millstone River and the Delaware and Raritan Canal Towpath (providing a geological barrier). Separate deer counts and density estimates were calculated for each of the two sections of the overall study area. Deer densities were later calculated by dividing the total number of deer confirmed by the size of the area surveyed in acres. Multiple missions were flown in both the East and West sections to cover the entire study areas. Deer heat signatures were visible and clear in most areas. ***See Figures 14 and 15***.

On the night of November 22 and early morning of November 23, 2019, between the hours of 9:00 p.m. and 4:00 a.m., 41 flight missions were completed, 18 missions in HMFC and surrounding areas of Franklin Township and 23 missions in Hillsborough Township. Areas were covered systematically, with 2 *Pilots in Command* (PICs), 3 *Visual Observers* (VOs), and NJAES/RCE and HMFC teams. On the night of March 4 and early morning of March 5, 2020, between the hours of 9:00 p.m. and 1:00 a.m., 9 flight missions were completed in the Hillsborough Township section of the study area. The following night, March 5 and early morning of March 6, 2020, between the hours of 7:30 p.m. and 2:00 a.m., 16 flight missions were completed in the HMFC Franklin Township study area. Areas were covered in the same method as the November 2019 surveys, with one PIC, 1 VO, and NJAES/RCE and HMFC teams. In both survey components all 66 missions were conducted safely. Conditions were excellent as the ground temperatures were cool and the skies were clear. Deciduous trees were void of leaves except for some oaks (*Quercus sp.*) and patches of autumn olive (*Elaegnus umbellate*) in the November 2019 survey. E*vergreen tree* coverage was minimal in some areas and moderate to heavy in others, particularly the Eastern red cedar (*Juniperus virginiana*) groves. Images were collected using a VTOL sUAS with high-resolution visual imaging thermal infrared sensors flying manual missions to ensure complete coverage of the study area, adequate *image overlap*, and *repeatability*. Various thermal filters were utilized in flight to highlight the intended heat signatures. ***See Figures 11 and 12.*** The *small Unmanned Aerial Vehicle* (sUAV) was equipped with FAA compliant lighting visible to 3 statute miles. ***See Figure 9.***

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.

Esri Data Collector was used in the field to record numbers, map geographic locations of deer and make field notes. This method is becoming increasingly more dependable for the population density data collection of *ungulates* (Chabot and Bird 2015). Thermal imagery was analyzed both in the field and later in the lab to confirm deer heat signatures. Only confirmed deer images were used to provide conservative deer density estimates. Signatures that were considered to "likely" be deer yet could not be confirmed were not included in counts or density estimates for this study. ***See Figures 16 and 17***. Additionally, deer counts could not take place underneath evergreen trees or other obstructed areas where deer heat signatures could not be seen.

Figure 9*. Data collection crew landing sUAS.*

***Species* Identification**

A trained wildlife biologist or experienced professional performed the analysis to ensure deer are confirmed and distinguished from other animals such as cattle, horses, sheep, goats, fox, raccoon, and coyote. Scale, location, and behavior are 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. ***See Figures 16 and 17.***

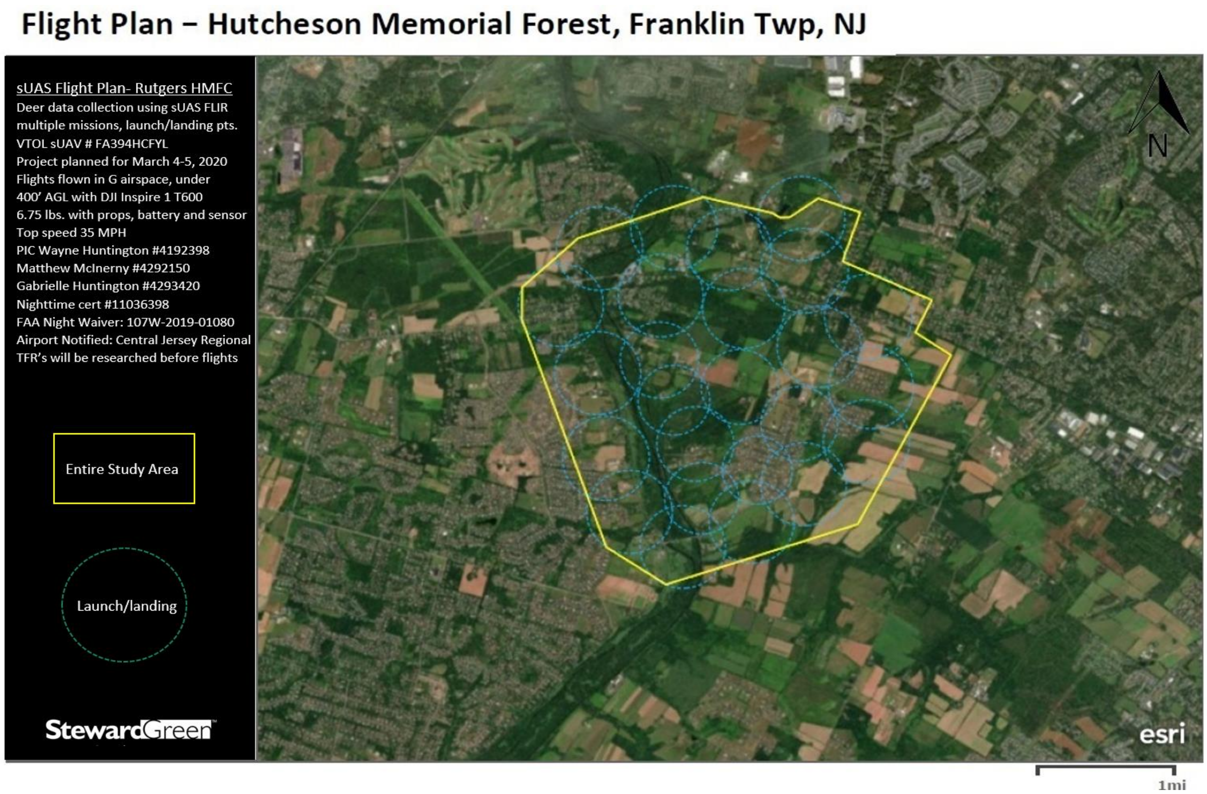


Figure 10. ***Preparation***: *Flight Plan, required by FAA, is a component in providing the necessary information for sUAS operations.*

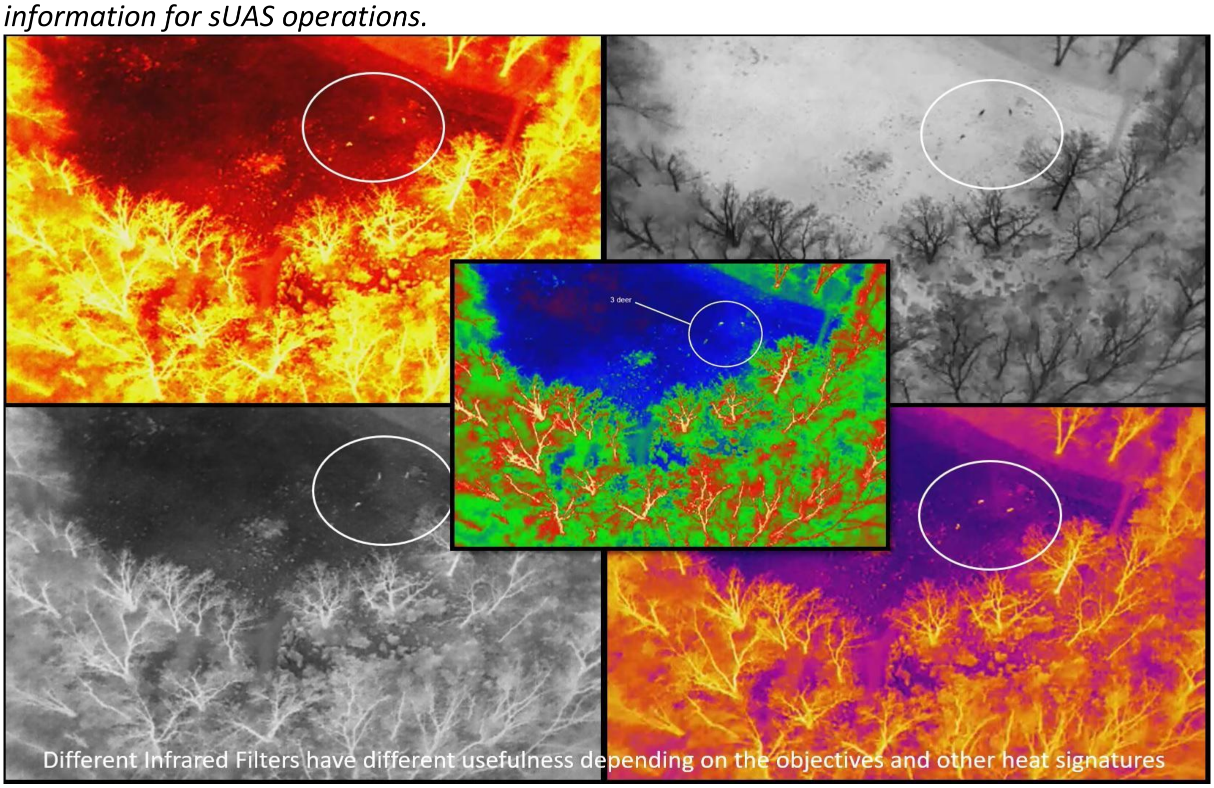


Figure 11. *Same 3 deer observed through 5 different infrared filters demonstrating visual usefulness of the technology.*

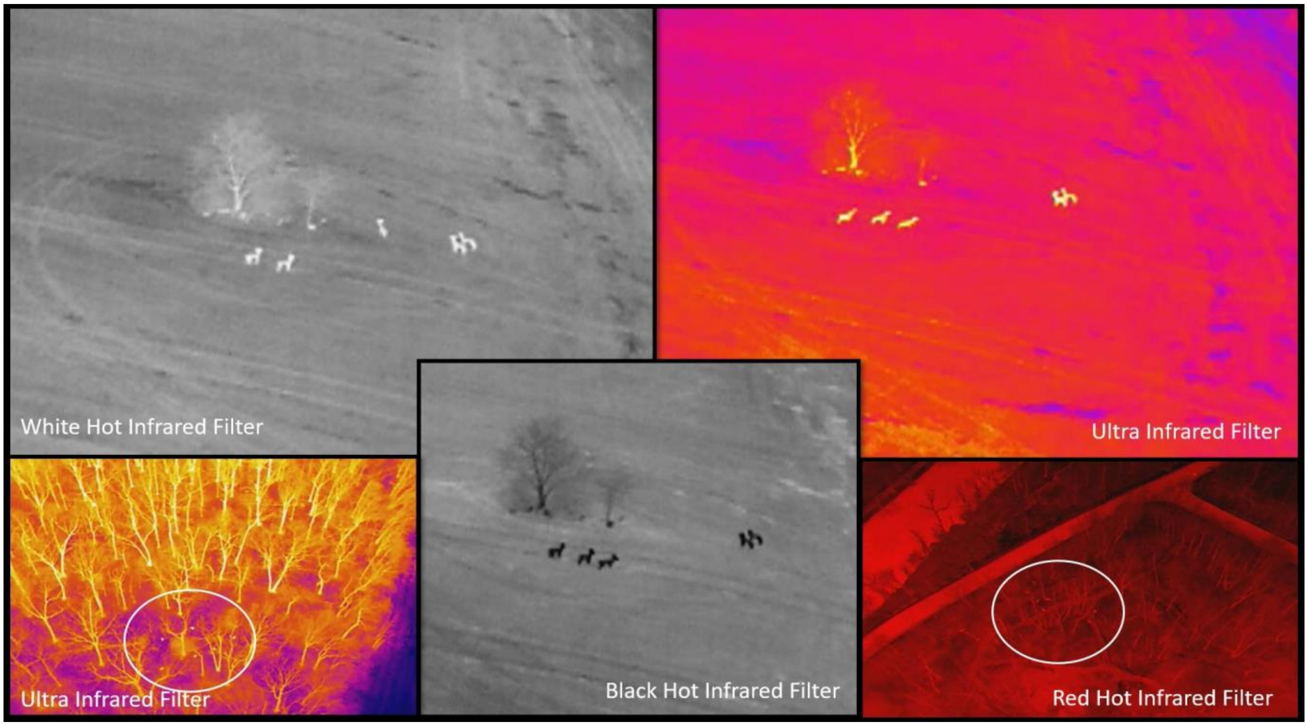


Figure 12. *Different infrared filters can help visualize the heat signatures. These are all deer heat signatures.*

Figure 13. *sUAS flight paths indicate sUAV flight pattern, yet also the sUAV hovers and yaws, or turns radially, to "see" in different directions.*

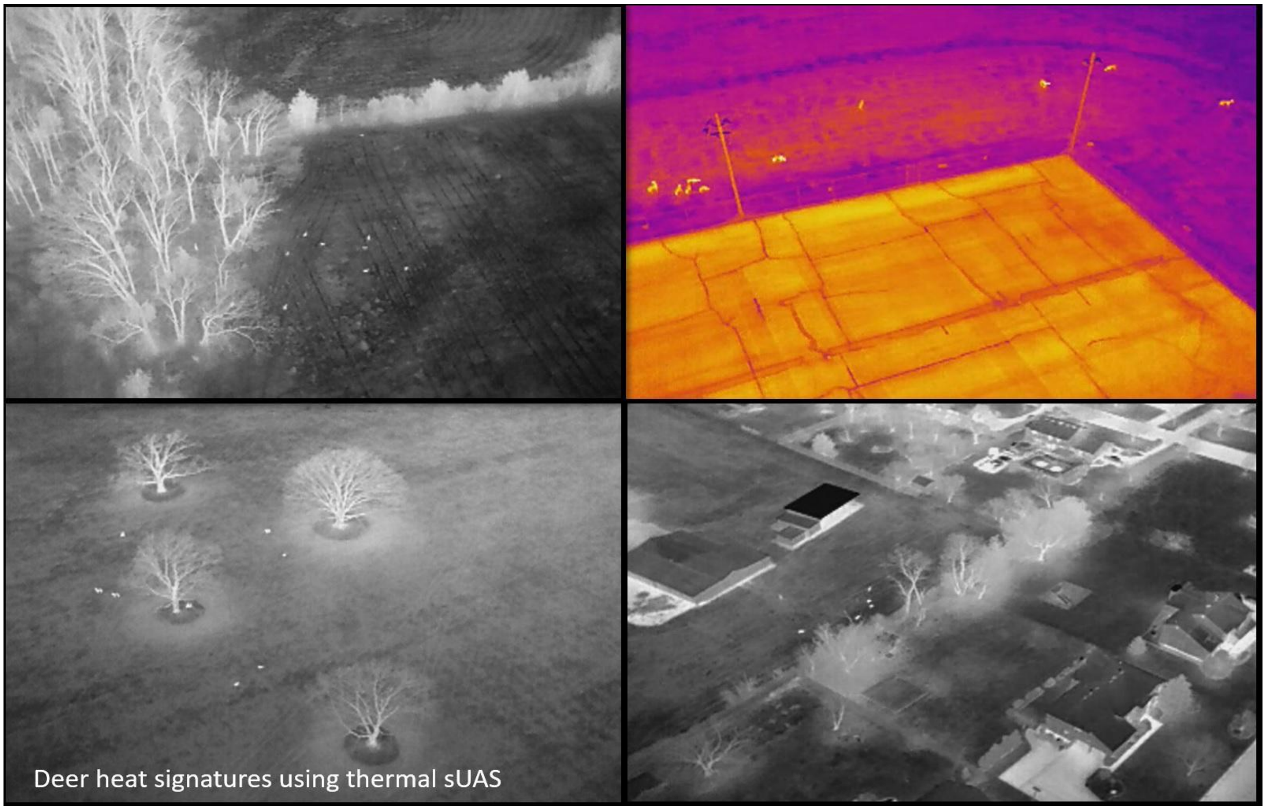


Figure 14. Overcount prevention*; Heat signatures identifying deer were clear and visible.*

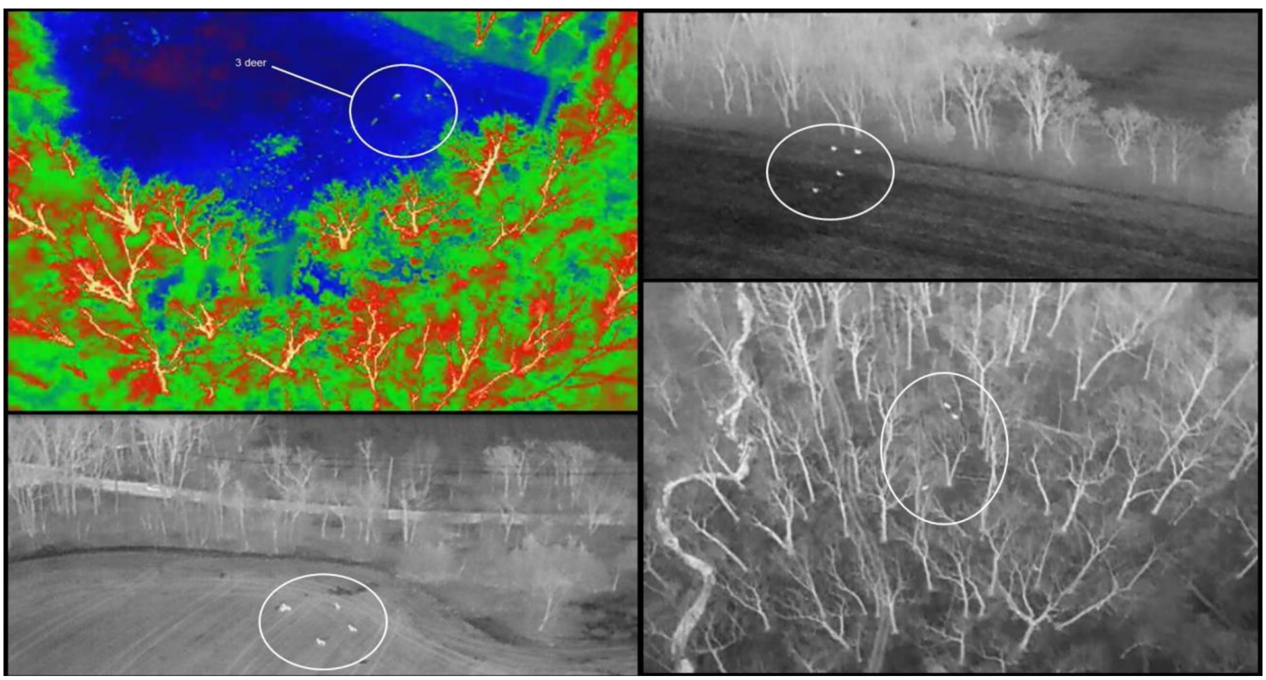


Figure 15. *Heat signatures identifying deer were clear and visible in agricultural fields as well as woodlands.*

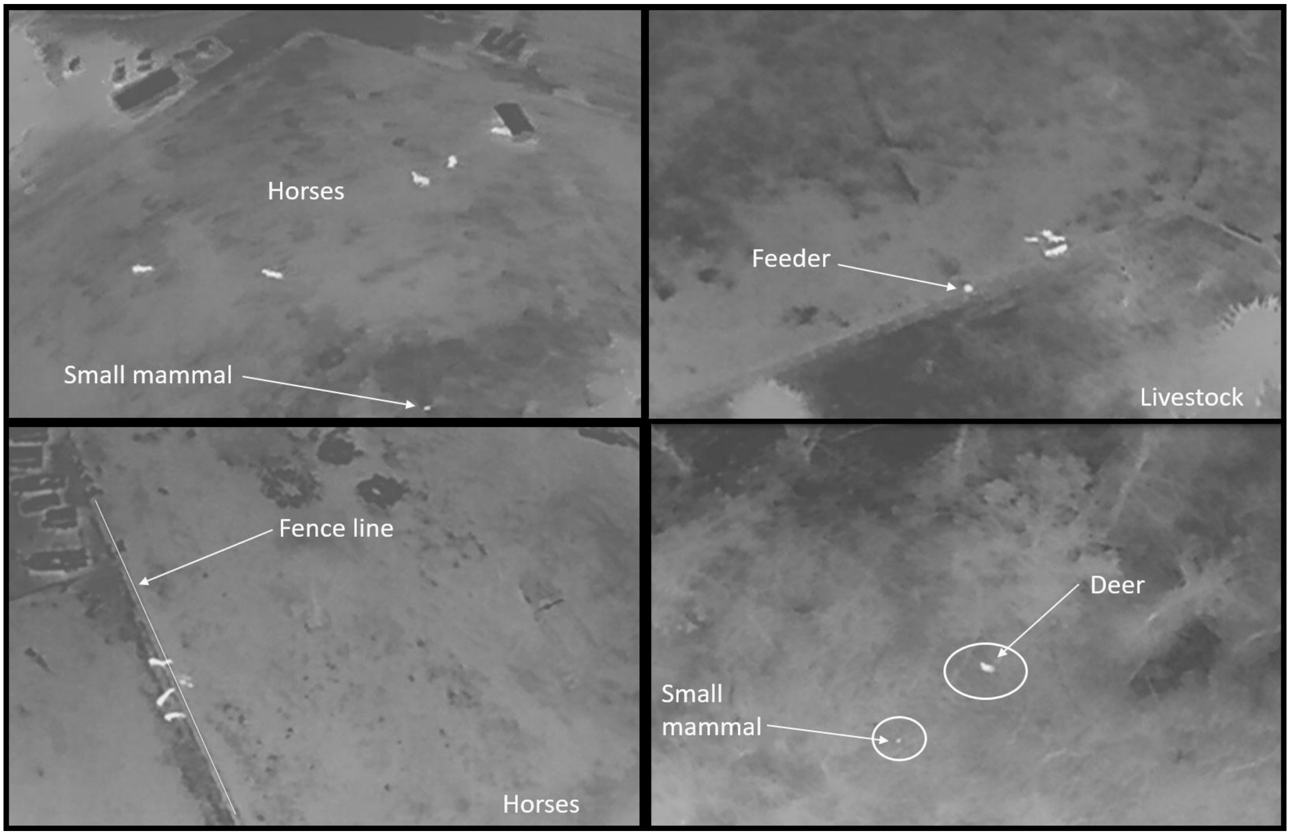


***Figure 16. Species identification**: Note different species have different thermal signatures.*

***Figure 17. Species identification:** Horses, goats and cattle are examples of ungulates not to be confused with deer. A trained wildlife specialist can distinguish them.*

Project Challenges
Minor technical difficulties were overcome in the field, such as cold batteries and tablets and signal interference from obstructions. 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 November 2019 survey. Although some of the oak trees retained their leaves in 2019, 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. Stray voltage interference is always a concern when working around high voltage lines. However, flights were performed at an altitude elevated enough that power lines were not a problem during these surveys.

Other heat signatures observed included boulders, field springs, pockets of water, ponds, streams, manhole covers, streetlights, active chimneys, drain inlets, electric transformers (ground and pole mounted), cars, junk lots, livestock, raptors, waterfowl, and other mammals. ***See Figures 18 and 19.***

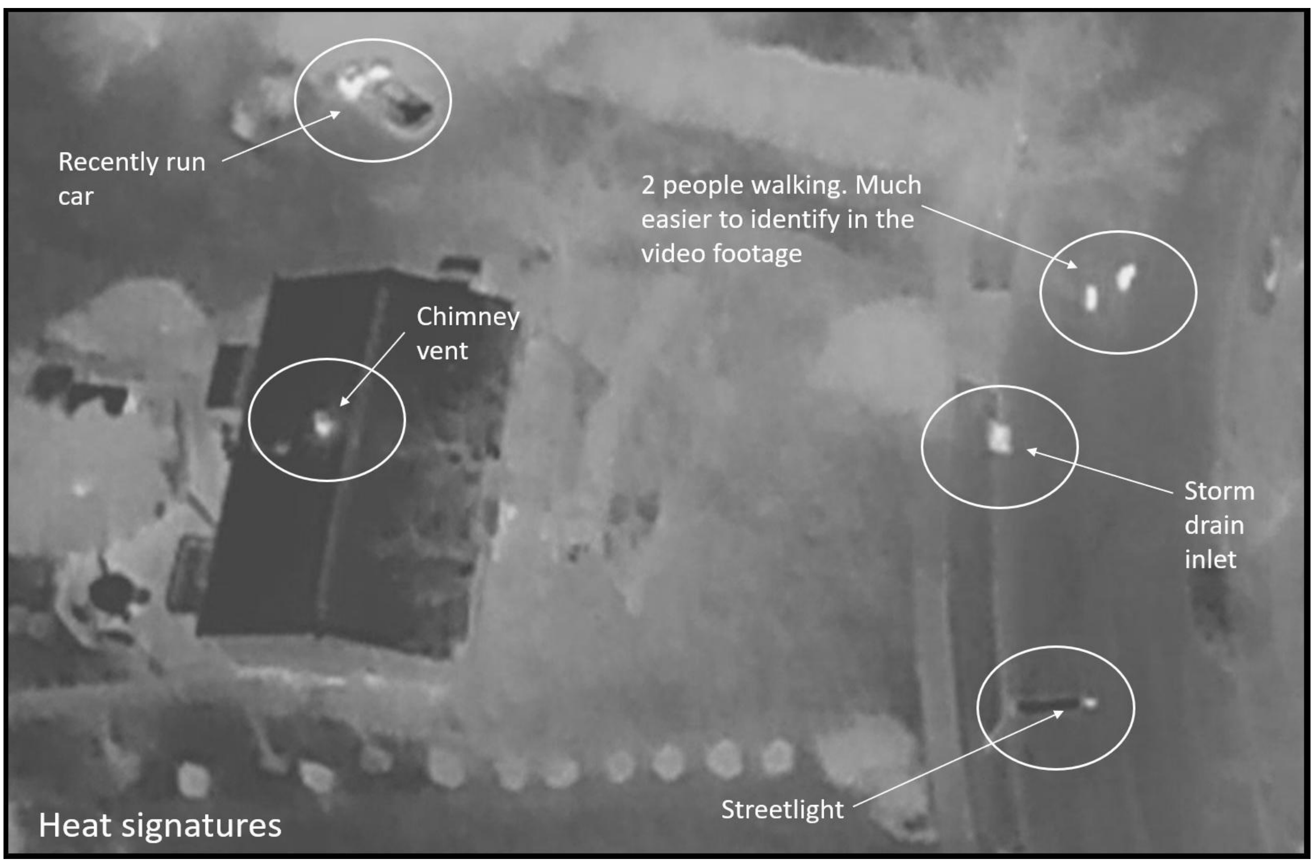


Figure 18. Species identification: *Examples of other types of heat signatures from just one image. It is important a professional thermal analyst review the data.*

Figure 19. *Examples of different heat signatures.*

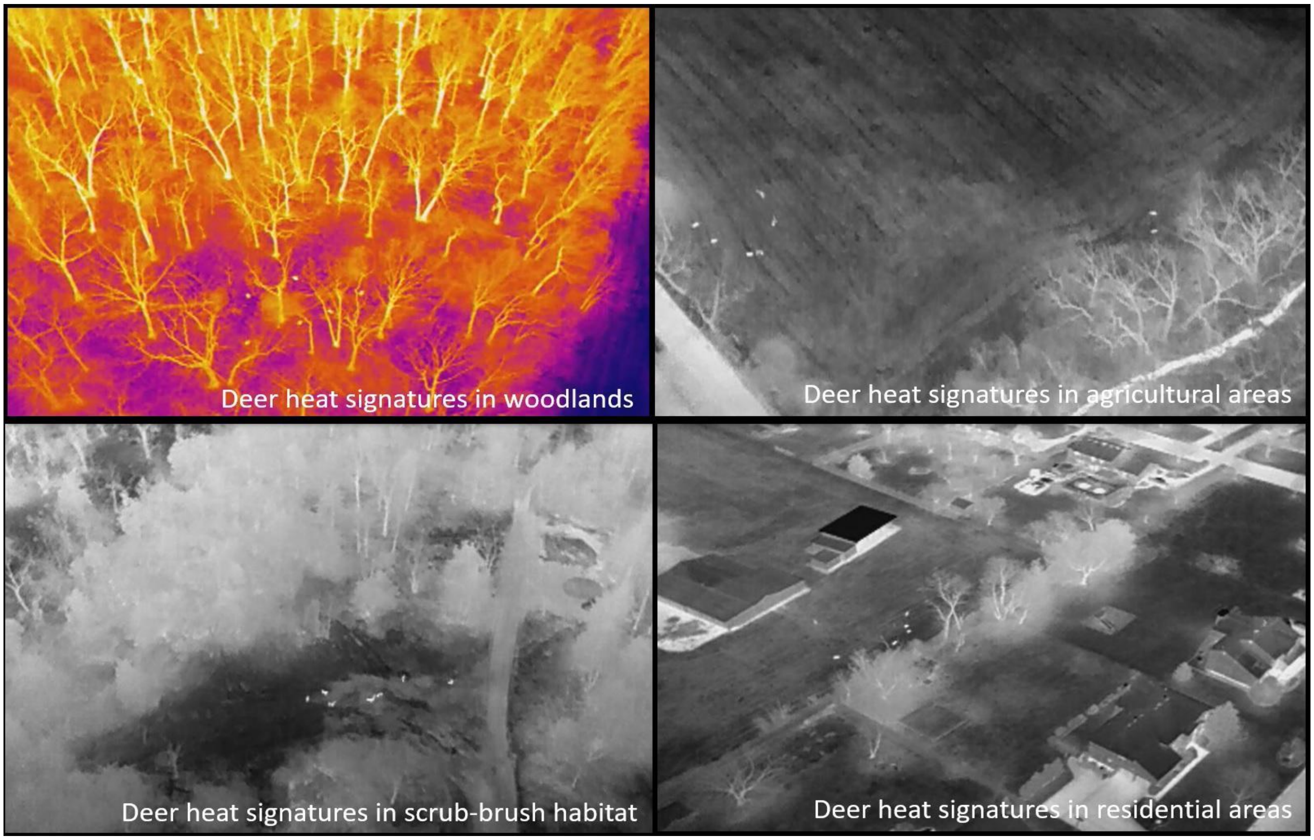


Figure 20. *Examples of deer heat signatures in different habitats, agricultural and residential areas.*

HMFC Deer Fence Exclosure

A fence was installed around 85 acres of forest in 2015 to protect the forest ecosystem from excessive deer browse that 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.

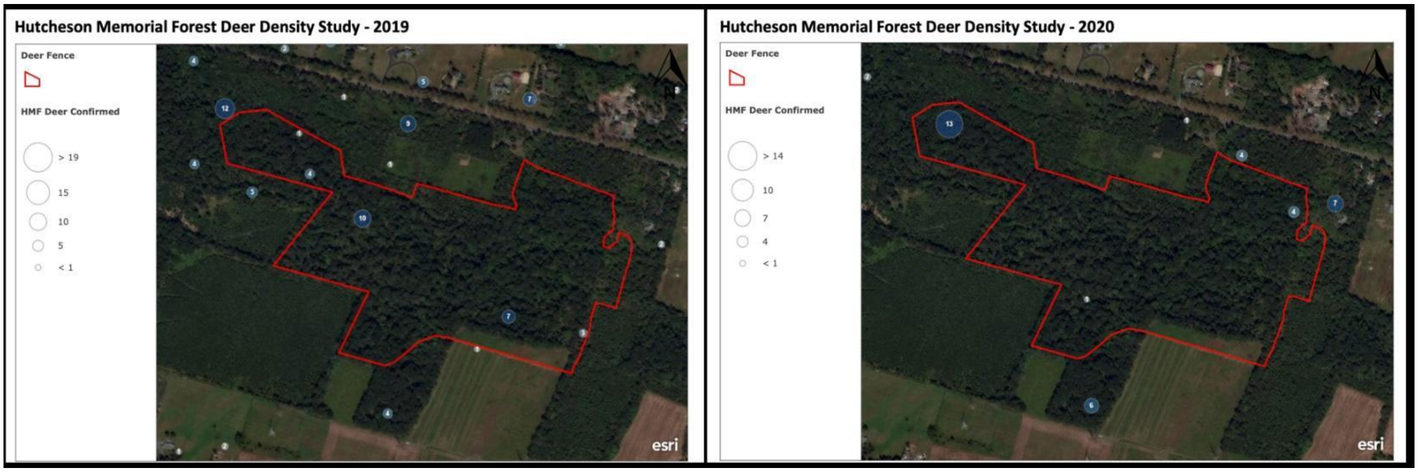


Figure 21. *HMFC Fenced area deer observed, 2019 and 2020.*

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. During the November 2019 survey 25 deer were confirmed inside the exclosure and 18 deer were observed during the March 2020 survey. The fence has since been repaired and additional proactive forestry management activities have been implemented to decrease future damage, but fence repair will be an ongoing issue.

Results

HMFC & Franklin Township (East)

Findings yielded a confirmation of 531 deer counted, which equates to 147 deer per square mile for areas covered in the November 2019 data collection. In March 2020, 305 deer were confirmed in all the sampling areas combined, which equates to 77 deer per mi². ***See Table 2.***

Hillsborough Township (West)

Findings west of the D&R Canal yielded a confirmation of 164 deer counted in all the sampling areas combined, which equates to 104 deer per square mile for areas covered in the November 2019 data collection. In March 2020, 73 deer were confirmed in all the sampling areas combined, which equates to 45 deer per mi². ***See Table 2.***

Rutgers Hutcheson Memorial Forest Center *White-tailed deer population density results*					
Area collected	Dates flown (data collected)	Confirmed # of deer	Confirmed deer/mi²	Acreage Covered	# of Missions
HMFC & Franklin Twp (East)	Nov 22 & 23, 2019	531	147	2317	18
HMFC & Franklin Twp (East)	March 5 & 6, 2020	305	77	2534	16
Hillsborough Township (West)	Nov 22 & 23, 2019	164	104	1011	23
Hillsborough Township (West)	March 4 & 5, 2020	73	45	1032	9

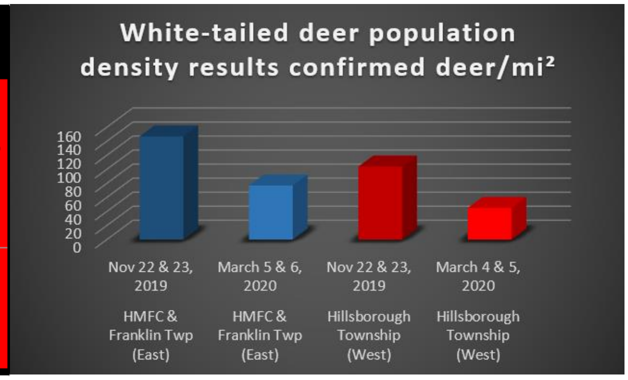


***Table 2.** HMFC White-tailed deer population density results*

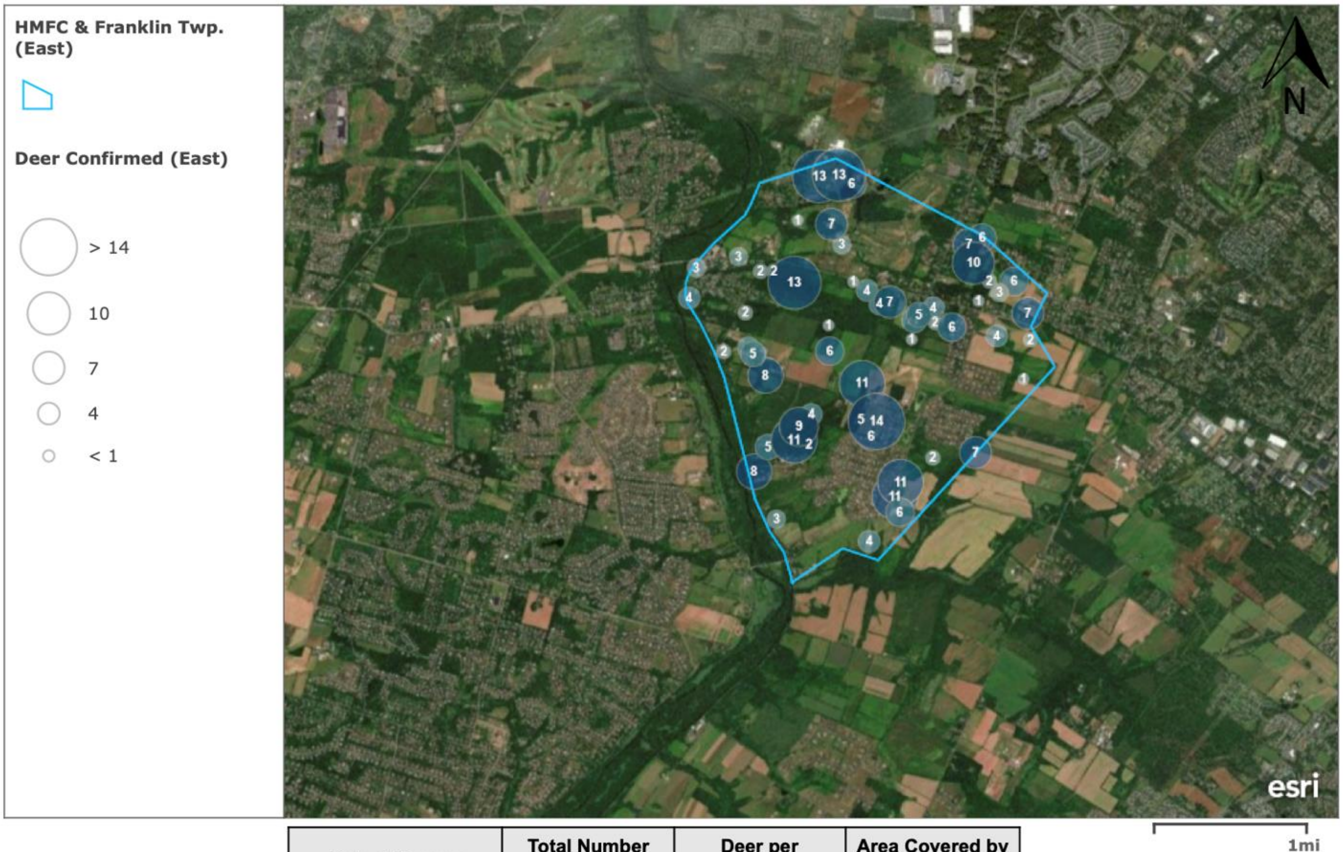
HMFC & Franklin Twp. (East) - 2019

StewardGreen

Date of Survey	Total Number of Deer	Deer per Square Mile	Area Covered by sUAS (Acres)
Nov 22-23, 2019	531	147	2317

***Figure 22.** 2019 HMFC White-tailed deer population density mapping geographic locations of confirmed deer, HMFC and Franklin Township.*

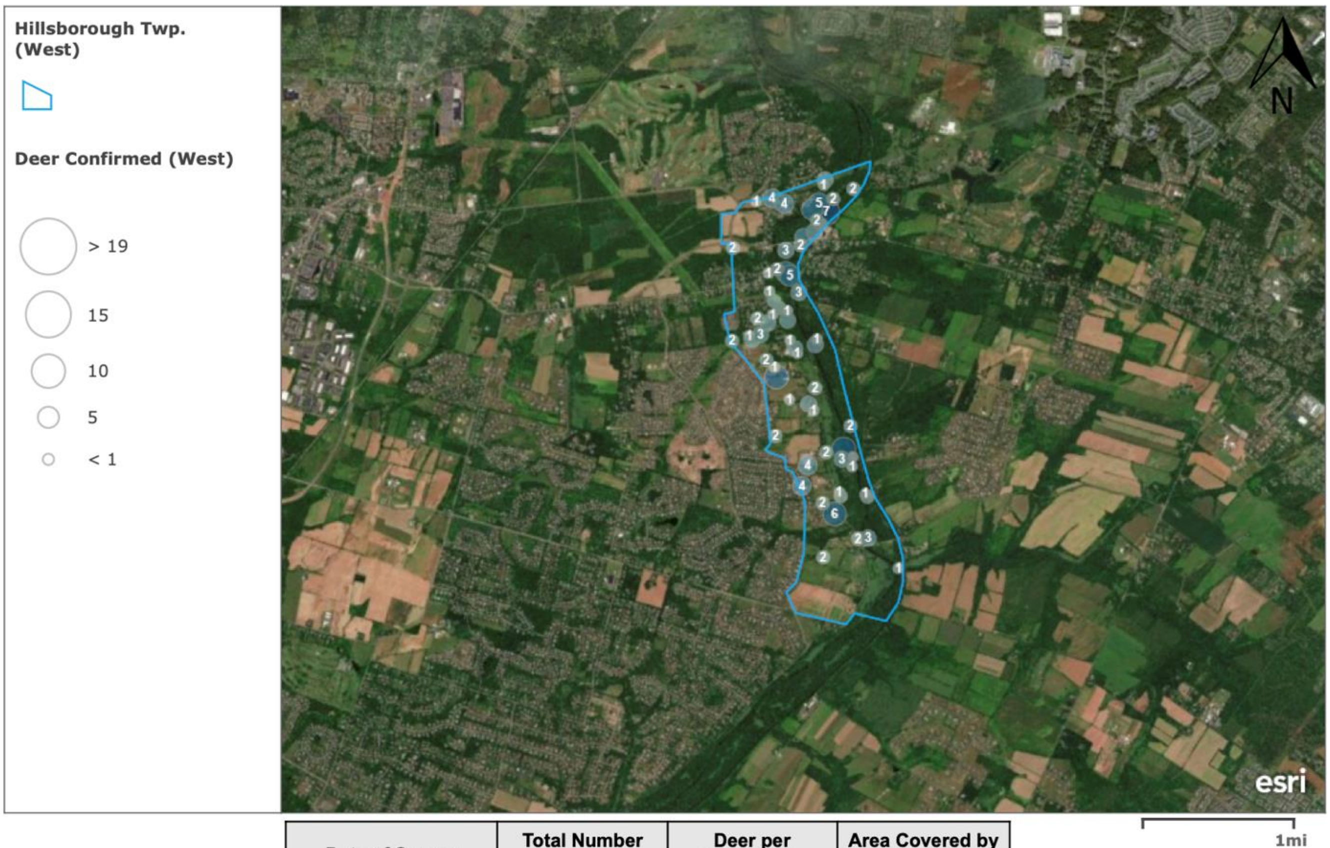
HMFC & Franklin Twp. (East) - 2020



Date of Survey	Total Number of Deer	Deer per Square Mile	Area Covered by sUAS (Acres)
Mar 5 & 6, 2020	305	77	2534

Figure 23. *2020 HMFC White-tailed deer population density mapping geographic locations of confirmed deer, HMFC and Franklin Township.*

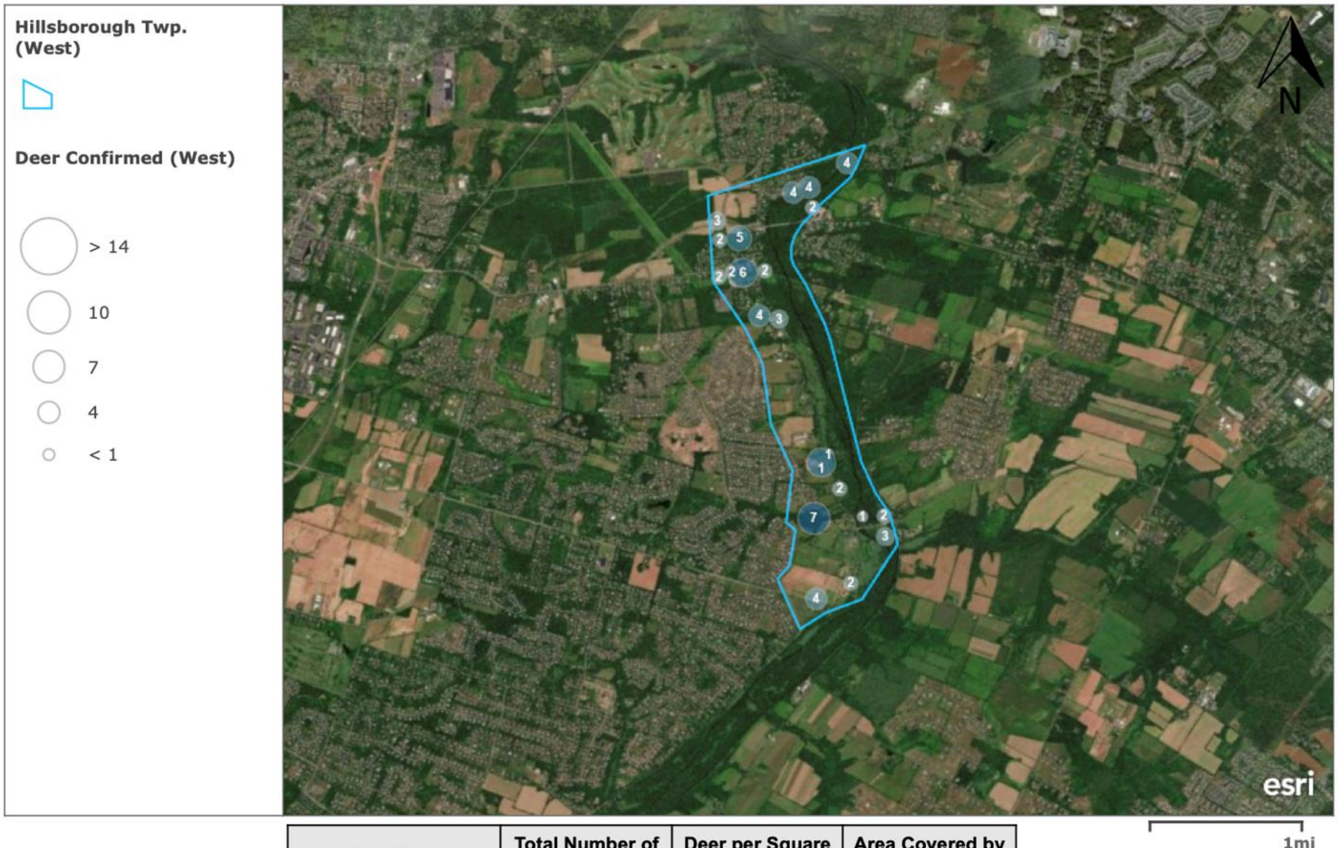
Hillsborough Twp. (West) - 2019



Date of Survey	Total Number of Deer	Deer per Square Mile	Area Covered by sUAS (Acres)
Nov 22&23, '19	164	104	1011

Figure 24. *2019 HMFC White-tailed deer population density mapping geographic locations of confirmed deer, Hillsborough Township.*

Hutcheson Memorial Forest Deer Density Study - 2020



Date of Survey	Total Number of Deer (Confirmed)	Deer per Square Mile (Confirmed)	Area Covered by sUAS (Acres)
Mar 4 & 5, 2020	73	45	1032

Figure 25*. 2020 HMFC White-tailed deer population density mapping geographic locations of confirmed deer, Hillsborough Township.*

Adding value, a similar study, commissioned by New Jersey Farm Bureau in 2019, was performed in eight counties in NJ, including other areas of Franklin and Hillsborough Townships in Somerset County. These areas were surveyed in April 2019. The Franklin Township study area is to the southeast of the HFMC and approximately 1,208 acres or 1.89 square miles. ***See Figure 26.*** Total number of deer confirmed were 154, or 82 deer per square mile. The Hillsborough Township study area to the southwest is approximately 2 miles from HMFC and approximately 1,626 acres or 2.54 square miles. Total number of deer confirmed were 248, or 98 deer per square mile.

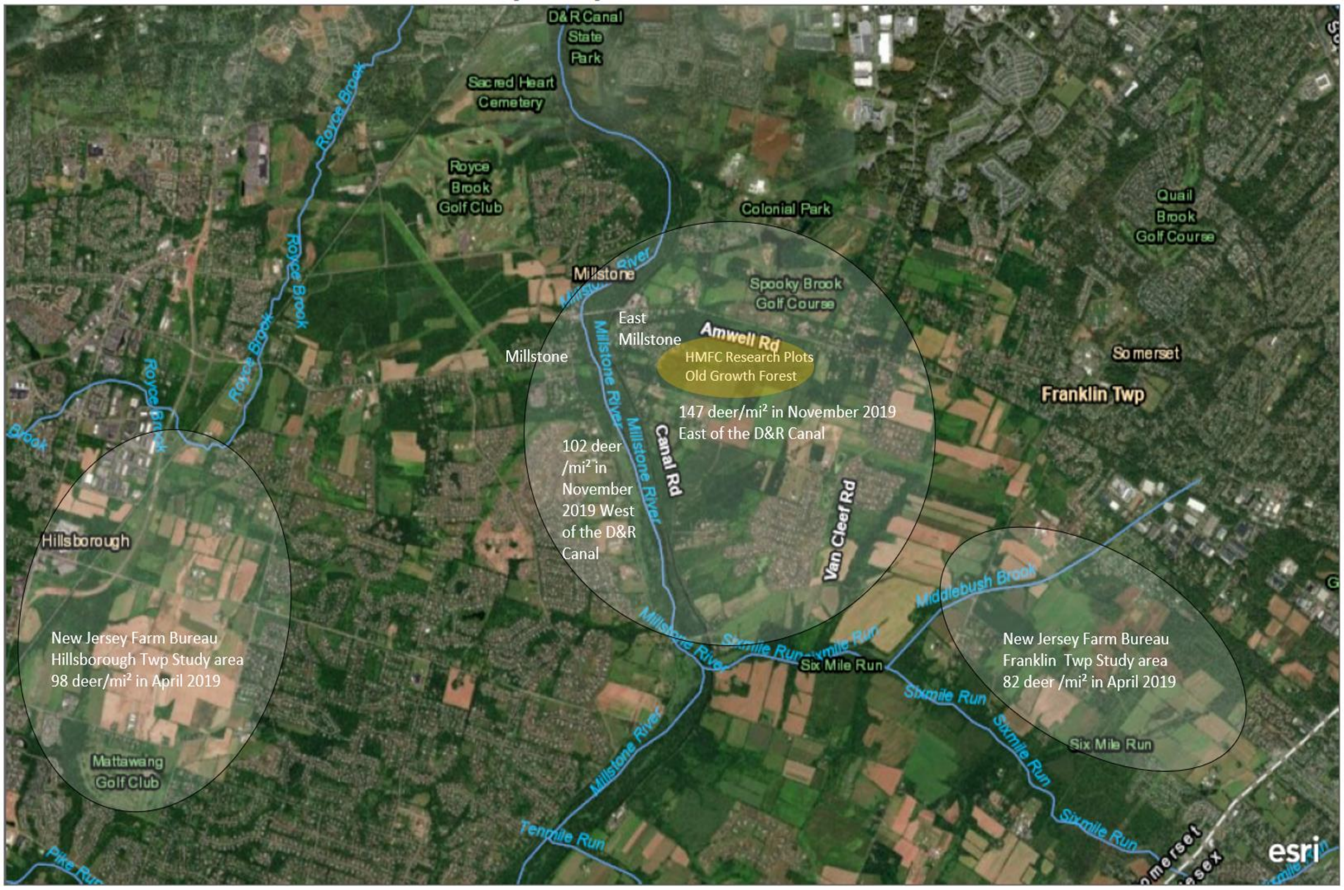


Figure 26. *New Jersey Farm Bureau study areas in Somerset County from 2019. Both areas are in HMFC range for deer.*

Differences Between Surveys

Differences between the November 2019 and March 2020 surveys may have been the result of several contributing factors. Participants in the deer management program were regularly active on the HMFC properties and harvested 37 deer, over 80% of which were female, between November 23, 2019 and February 15, 2020. An unknown number of deer were also harvested through hunting on private lands in the area and through the implementation of farmer depredation permits. Temporary changes in deer ranges may have also been a contributing factor. In landscapes similar to the study area that included a mixture of forested, agricultural and residential housing, where habitat patches are connected, deer have exhibited seasonal changes in activities including expansions of ranges during and following hunting seasons (Rhoads et al. 2010). November is also the peak of the breeding season when male deer will extend their range.

Conclusion

Although management objectives for deer in suburban areas are commonly less than 20 deer/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/square mile. 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 (Boulander 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.

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 November 2019 and March 2020 using thermal images obtained by sUAS. Data was recorded in the field using the Collector for ArcGIS data collection application. 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 been consulting clients for many years in thermal data collection, conservation, wildlife habitat regeneration, bioretention and ecosystem services development. Our lead consultant has been performing successful heat signature work since 2001, starting with helicopter, then airplane mounted Forward-Looking Infrared (FLIR). In 2013, we started using sUAS with thermal infrared sensors as the technology became more reliable, the data collected with 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 and data analysis. The New Jersey Division of 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.