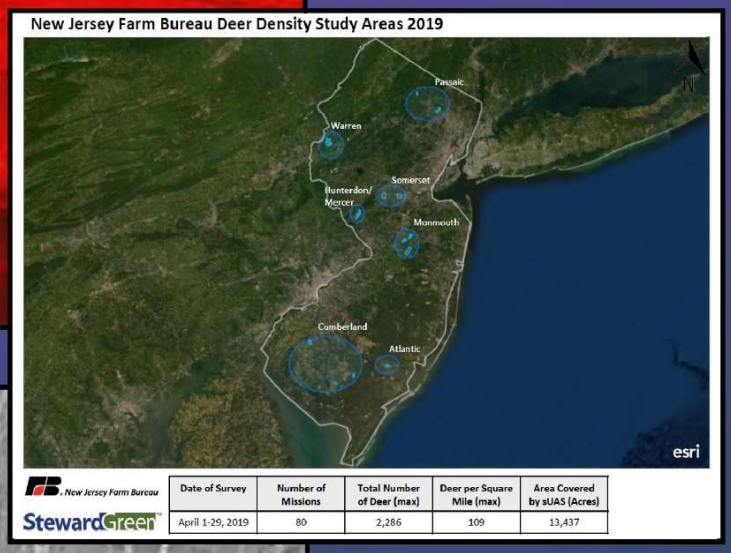
New Jersey White-Tailed Deer (*Odocoileus virginiana*) Population Density Survey using sUAS Infrared; New Jersey Farm Bureau - 2019 Study



Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 1-29, 2019	80	2,286	109	13,437

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FOREWARD

The following report and survey of deer population densities in New Jersey was commissioned by the New Jersey Farm Bureau as part of an overall initiative concerning deer over-population. Simple visual observations and anecdotal accounts from farmers across the state point to surplus deer at levels creating unacceptable impacts to residents, landowners and businesses in the state.

Farm Bureau's renewed efforts in this policy area surfaced in early 2018 with a ten-point questionnaire among its farmer members and a re-examination of the extensive studies by N.J. Agricultural Experiment Station at Rutgers University on deer over-population during 1998-2005. Questions arose about the actual number of deer throughout the state, whether deer numbers were uniform or concentrated in certain areas, and how the game code administrators evaluated the deer herd size.

Drone (UAV-unmanned aerial vehicles) technology is gradually working its way into a variety of agricultural management practices in recent years. One application is mounting an infrared camera to the drone for the purpose of identifying livestock and wildlife from low altitudes in the sky. This is a significant improvement in video quality and cost savings from helicopter-based deer counting that was employed by Rutgers AES in the late 1990's.

The first drone-based deer count sponsored by Farm Bureau was conducted by the Drone Academy on Dave Bond's farm near Ringoes in August 2018. That was followed by the same type of survey at the NJAES Snyder Research Farm in Pittstown (September) and the Stewart Farm in North Hanover (October). These flights were experimental, testing things such as the use of the technology/acquisition of FAA permits/establishing survey parameters/interaction with farmland owners/need for wildlife biology expertise/cost estimating/and so forth.

The deer counting project work transitioned to the wildlife habitat management firm of Steward Green from Bridgewater in early 2019. A plan of work was established that was farm-centric, statewide and representative of agronomic/landscape features of New Jersey agriculture. County Boards of Agriculture were consulted and some of their representatives became participants in the coordination of the drone flights; many county boards also contributed financially to the project.

As the data in the report shows, seven separate project flights covering eight counties (two were adjoining) and 12,730 acres (20 sq. mi.) were subject to the counting. Those results provide a baseline of data that can be expanded by other drone-based deer survey work using a methodology similar to that used by Steward Green. Work initiated by Farm Bureau in Burlington County will be completed in December '19-January '20; other agricultural areas can be done on an as-needed basis. It is hoped that municipalities, county parkland, corporate campus areas and forest landowners will contract for their own deer density surveys and thereby add to the emerging database.

This data collection work is essential as background information to the upcoming policy debates on deer management that need to happen in New Jersey.

Peter J. Furey, Executive Director
New Jersey Farm Bureau
October 2019

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New Jersey White-Tailed Deer (*Odocoileus virginiana*) Population Density Survey using sUAS Infrared; New Jersey Farm Bureau

Executive Summary. White-tailed deer (Odocoileus virginianus) garner more attention than any other species in New Jersey. Wildlife watchers, photographers, and hunters contribute millions of dollars each year to the state's economy while pursuing deer. At the same time, deer are responsible for New Jersey's agricultural producers and other citizens suffering millions of dollars' worth of damage to crops, landscaping and vehicles annually.

White-tailed deer were present in New Jersey at the time of settlement in the 1600s but by 1900, market hunting and habitat destruction had nearly extirpated deer from the state. A combination of wildlife laws, a changing landscape throughout the 20th century that resulted in abundant deer habitat, and reduced deer harvest has caused a drastic increase in deer numbers in New Jersey in recent decades.

It is going to take broad stakeholder engagement and commitment to a combination of varied recommendations in order to properly reduce New Jersey's deer herd to manageable levels.

New Jersey Farm Bureau (NJFB) contracted with Steward Green to complete a deer population density survey using drones in select agricultural areas of NJ that have historically experienced large economic losses due to deer overabundance. All nine areas that were sampled have deer populations far exceeding biological (BCC) and cultural carrying capacity (CCC); as seen by excessive landscape and agricultural damage, lack of forest regeneration, and increases in invasive species, automobile collisions and prevalence of Lyme disease.

The results of the drone flights suggest that at a minimum there were 2,047 deer counted in the sampling areas, which equates to 103 deer per square mile for areas covered in the data collection. At maximum there were 2,210 deer counted in the sampling areas, which equates to 111 deer per square mile for areas covered in the data collection.

Deer population levels are currently not compatible with the varied interests of NJ citizens. Large numbers of deer are harbored on both private and public lands that do not allow hunting. As an evolutionary prey species, deer exhibit a high fecundity rate, enabling them to rapidly increase in number. Presently, non-lethal management techniques (such as contraceptives) and lethal management techniques (such as recreational hunting) are not adequate to regulate NJ's overabundant deer population, nor is non-hunting mortality (disease, injury and predators) enough to reduce the herd to satisfactory levels.

It is obvious that New Jersey needs a state-wide Deer Management Plan like all the surrounding states. A state-wide Community-Based Deer Management Coordinator would be instrumental in engaging municipalities and coordinating deer management to increase effectiveness. Greater hunter access to both public and private land is crucial, as are changes to liberalize the game code. Venison donation programs must be expanded, and some form of commercial hunting needs to be considered.

Objective. Provide NJFB white-tailed deer population density estimate in select agricultural areas throughout New Jersey.

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Study Areas. Areas sampled encompassed (7) study areas totaling approximately 12,730 acres, or 20 square miles, consisting of a mix of upland woodland, agricultural fields, residential, fragmented woodland parcels, wetlands and minor open water. Sample areas were within Atlantic, Cumberland, Gloucester, Hunterdon, Mercer, Monmouth, Passaic, Salem, Somerset and Warren Counties, New Jersey, *See Figure 1*. These areas were chosen because of their varied agricultural uses and the deer damage reported at County Board of Agriculture meetings.

Figure 1. **NJFB Deer Population Density Study Areas**.

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Methodology. Steward Green LLC (SG) is providing NJFB with infrared thermal digital aerial imagery analysis and reporting within the study areas. The intent of the data collection is 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 collecting imagery that will best indicate white-tailed deer heat signatures. Optimum data collection is during the night and during colder months before the deciduous trees have produced leaves, as the infrared sensors easily penetrate to the ground. Also, the colder ground temperatures contrast greater with heat signatures produced by deer. In areas that are currently managed or hunted, deer have "settled" again after late February, making late February to late April an ideal time to collect data in managed or hunted areas. The infrared heat signatures produce a reliable method of "counting" the deer in analysis by an experienced, skilled technician. Vertical Take-Off and Landing (VTOL) Unmanned Aerial Systems (UAS), or drones, were used legally and safely to collect the data. Flights were conducted manually to produce the best results, as using this method allows the technician to pause, hover, circle areas, zoom and even change the oblique sensor angle when there are questionable heat signatures behind structures, underneath cover, grouped together, etc. This is different from traditional methods using fixed wing airplanes that fly strip transects with fixed optics. Flights were completed less than 400' above ground level (AGL). Equipment was calibrated in the field to ensure geographic accuracy. Geo-referencing was performed in the field for accurate locations, vegetation type and mapping. Analysis was performed both in the field and afterward in the lab to determine the number of deer counted in the study. ESRI Data Collector was used in the field to record numbers and make field notes. This method is becoming increasing more dependable for the population density data collection of ungulates (Chabot and Bird 2015). With a trained wildlife biologist or experienced professional performing the analysis, deer can be distinguished from other ungulates such as cattle, horses, sheep, goats, etc., and other mammals such as fox, raccoon and coyote. Scale, location and habit are the main determining factors.

Table 1. **New Jersey Counties Summary NJFB Deer Population Density Study 2019**.

New Jersey Farm Bureau

White-tailed deer population density

StewardGreen

County	Municipality	Date	Acreage	Max. no. deer	Min. no. deer	Croplands	Woodlands	Residential	Industrial	Max deer/SM	Min. deer/SM	# of Missions
Atlantic	Galloway Township	April 16 & 17	557	169	161	88	44	29	0	194	185	5
Cumberland	Vineland, Buena Vista	April 16 & 17	1520	255	245	92	124	24	5	107	103	11
Hunterdon/Merce	East Amwell & Hopewell	April 27 & 28	1659	231	230	58	136	36	0	89	89	11
Monmouth	Millstone Township	April 17	3390	350	344	184	106	42	12	66	65	9
Passaic	West Milford & Wayne	April 23, 28- 29	940	81	65	15	41	8	1	55	44	12
Somerset	Hillsbrough & Franklin	April 3-5	2834	446	402	265	63	49	29	101	91	21
Warren	White, Harmony & Franklin	April 1 & 2	1830	678	600	392	85	119	0	237	210	11
		Totals:	12730	2210	2047	1094	599	307	47	111	103	80

Requirements. SG is approved to perform Unmanned Aerial System (UAS) operations based on our certifications with Federal Aviation Administration (FAA) and standard procedures. Missions were performed below 400' Above Ground Level (AGL). UAS data was collected legally and safely. Before any small Unmanned Aerial System (sUAS) flights were conducted, SG determined whether there were any Temporary Flight Restrictions (TFRs) issued by FAA. These were nighttime operations, that required additional FAA nighttime pilot certifications, which SG possess. Additional FAA waiver authorization was also required for nighttime flights, which are also maintained by SG.

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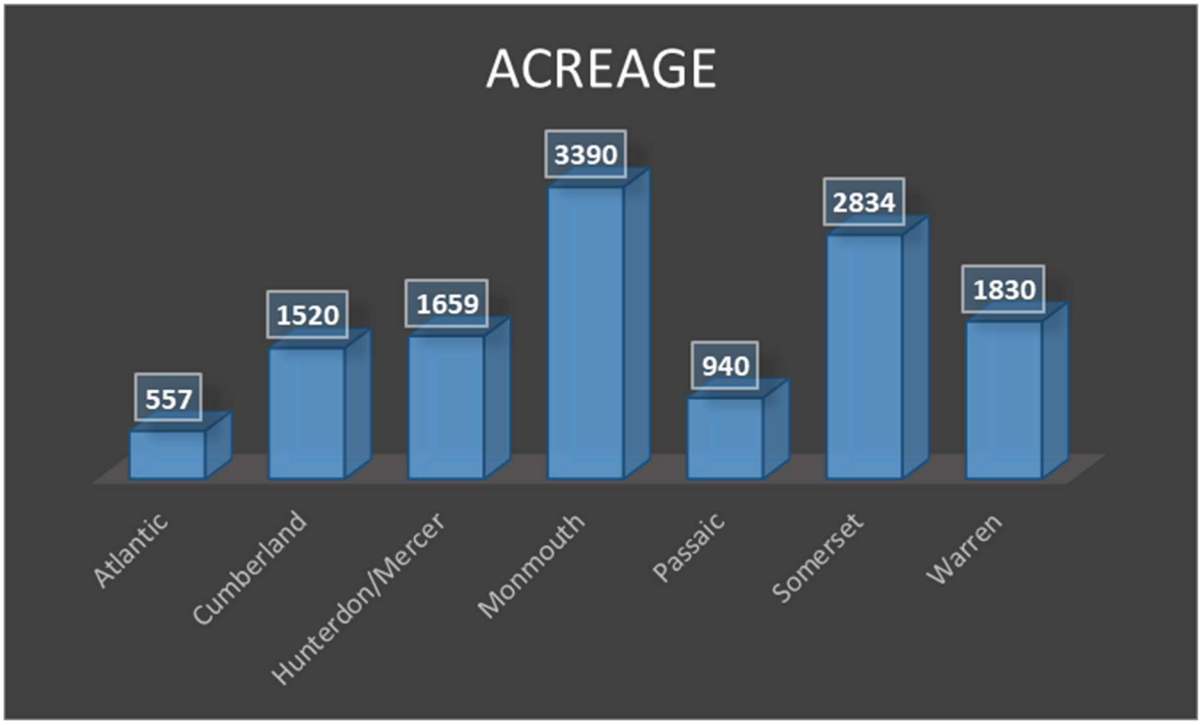
Table 2. New Jersey Counties Acreage covered in NJFB Deer Population Density Study 2019



Process. Site reconnaissance included FAA mandatory daytime inspections of the project areas to evaluate ingress/egress, potential launch/landing points, site hazards, obstructions, flight patterns, high voltage electric lines and towers, cell phone and radio towers, water towers, severe changes in elevation, large trees, etc. Launch/landing sites were also pre-determined. Over 80 missions were conducted safely between the hours of 8 PM and 7 AM April 1 through 29, 2019, covering areas systematically, with one Pilot in Command (PIC), Visual Observer (VO), an observer familiar with the land and small Unmanned Aerial Vehicles (sUAVs). Conditions were excellent as the ground temperatures were cool enough to provide excellent contrast and the skies were clear. Deciduous trees had not yet leafed out and evergreen tree coverage was minimal in most instances. Other heat signatures observed included boulders, field springs, pockets of water, streams, streetlights, active chimneys, drain inlets, electric transformers, cars in driveways, pets and other mammals. These signatures were quite different from those of deer. Images were collected using a Vertical Take-Off and Landing (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. Quality saturation data collection of the project area was completed, encompassing approximately 12,730 acres or 20 square miles. Deer heat signatures were visible and clear.

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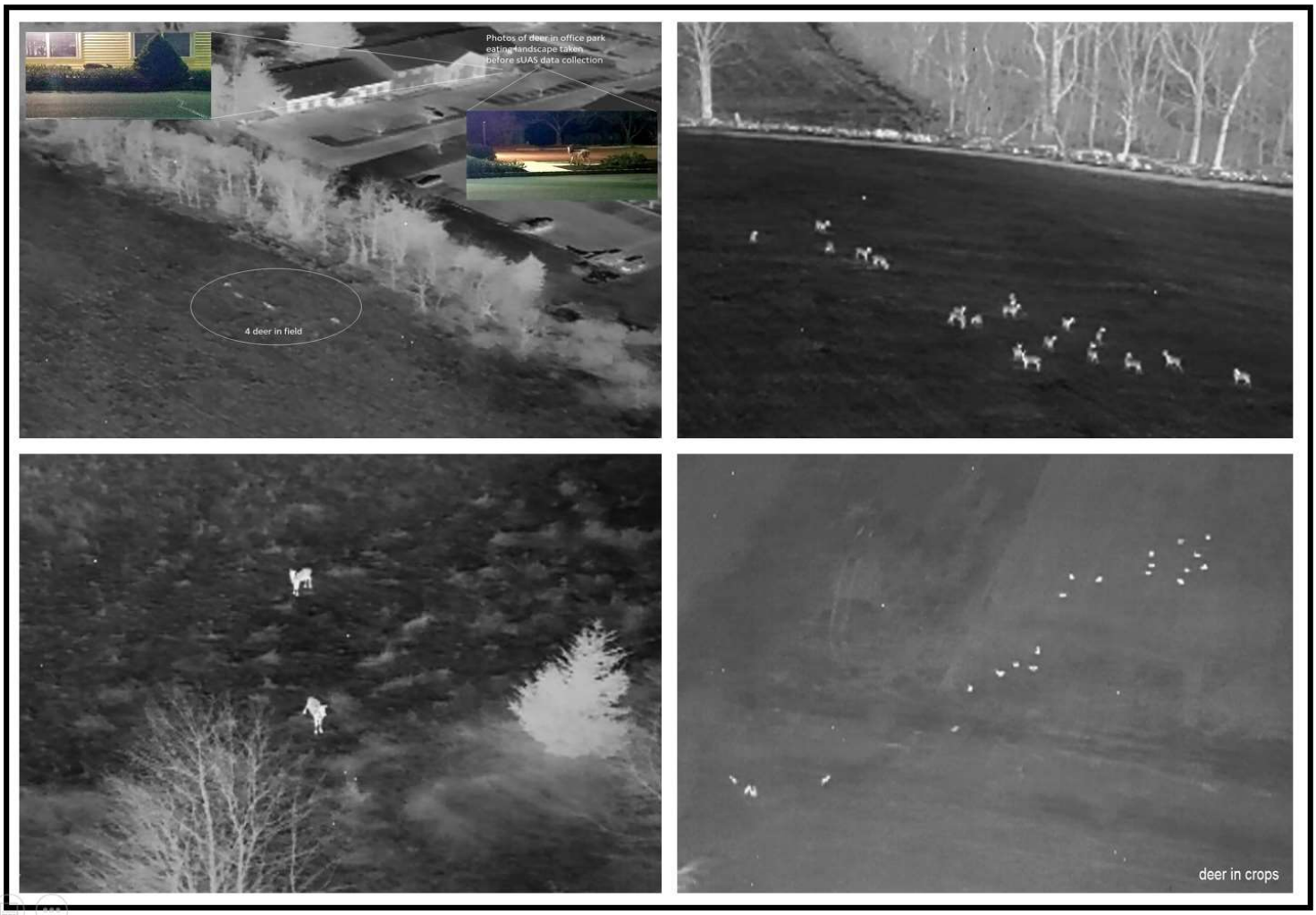
Figure 2. **Examples of deer heat signatures in agricultural fields**



Thermal imagery was analyzed both in the field and then more thoroughly in the lab to determine accurate heat signatures of deer. A minimum, or "deer confirmed" and a maximum, or "deer possible" count from the analysis of the data was also performed. The minimum count includes deer confirmed from the data, while the maximum count includes deer counted that were likely, but not confirmed as deer. The number counted as minimum is based on a few factors; that the deer counted was confirmed a deer by an experienced professional/wildlife biologist, that the deer was indeed in character with a deer sighting (shape, size, scale, movement, etc.) and that the deer had not already been counted. As with any infrared data collection, there can be areas that are unseen, such as underneath evergreen trees, or other obstacles, where deer can be present yet not seen as a heat signature. Still, there are possible deer observed in the data collection that are not counted in the minimum deer analysis. *See Tables 1, 2, 3 and Figures 2 and 3.*

This information was then used to create geographic location maps with points of interest (the heat signatures of deer), mission and data information.

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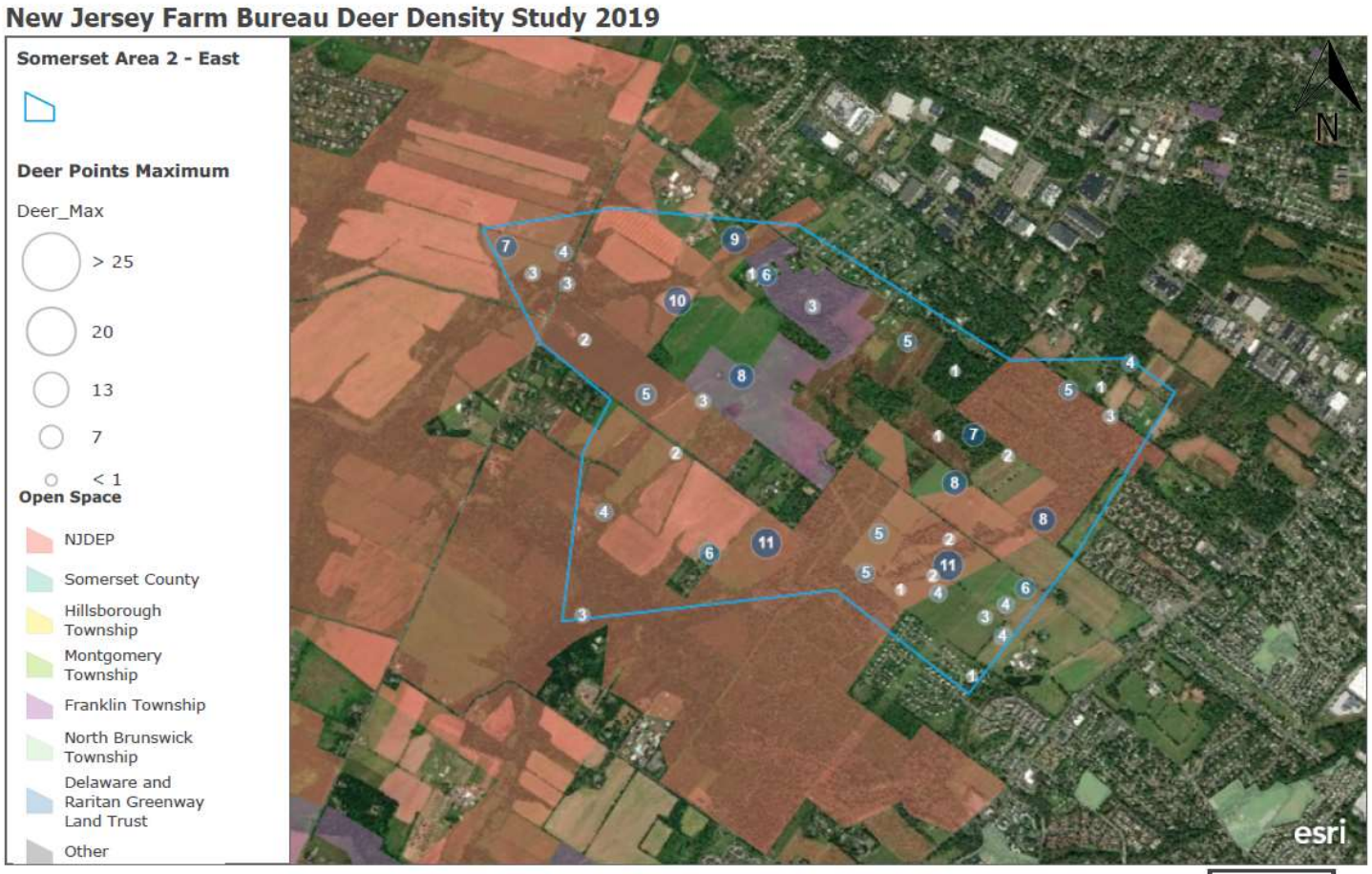
Figure 3. Example- **Maximum Deer Density Map Area 2 East, Franklin Township, Somerset County NJ**



New Jersey Farm Bureau

StewardGreen™

Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 4-5, 2019	11	178	94	1,208

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Table 3. Complete New Jersey Counties Summary NJFB Deer Population Density Study 2019

New Jersey Farm Bureau

White-tailed deer population density

StewardGreen

County	Municipality	Date	Acreage	Max. no. deer	Min. no. deer	Croplands	Woodlands	Residential	Industrial	Max deer/SM	Min. deer/SM	# of Missions
Breakdown:												
Atlantic County		April 16 & 17										
Area 1	Galloway Township	17-Apr	557	169	161	88	44	29		194	185	5
Cumberland		16-Apr										
Area 1 Northwest	Upper Pittsgrove Township	16-Apr	707	76	75	60	10	5		69	68	4
Area 2 East	Buena Vista Township	16-Apr	345	115	112	30	79	3		213	208	3
Area 3 South	Vineland, NJ	16-Apr	468	64	58	2	35	16	5	88	79	4
Hunterdon/Mercer		April 27 & 28										
Area 1 Northeast	East Amwell Township	27-Apr	691	97	96	25	60	11		90	89	3
Area 2 West	Hopewell Township	27-Apr	207	14	14		13	1		43	43	4
Area 3 Southwest	Hopewell Township	28-Apr	761	120	120	33	63	24		101	101	4
Monmouth		April 17 & 18										
Area 1 Northeast	Millstone Township	17-Apr	757	96	92	64	15	10	3	81	78	3
Area 2 West	Millstone Township	17-Apr	681	121	121	52	55	5	9	114	114	3
Area 3 South	Millstone Township	18-Apr	1952	133	131	68	36	27		44	43	3
Passaic		April 23, 28-29										
Area 1 Northwest	West Milford Township	April 23	255	27	24		18	5	1	68	60	6
Area 2 East	Wayne Township	28-Apr	278	9	5	5				21	12	2
Area 3 Southeast	Wayne Township	29-Apr	407	45	36	10	23	3		71	57	4
Somerset		April 3-5										
Area 1 West	Hillsborough Township	April 3-4	1626	268	248	151	30	36	29	105	98	10
Area 2 East	Franklin Township	April 4-5	1208	178	154	114	33	13		94	82	11
Warren		April 1 & 2										
Area 1 Northwest	White Township	1-Apr	150	70	56	5	9	42		299	239	2
Area 2 Northeast	White Township	1-Apr	175	153	131	72	34	25		560	479	2
Area 3 West	Harmony Township	2-Apr	1055	336	310	260	32	14		204	184	5
Area 4 South	Franklin Township	2-Apr	450	119	103	55	10	38		169	146	2
		State wide:	**12730**	**2210**	**2047**	**1094**	**599**	**307**	**47**	**111**	**103**	**80**
			20 Square Miles									

Results. At a minimum there were 2,047 deer counted in the sampling areas, which equates to 103 deer per square mile for areas covered in the data collection. At maximum there were 2,210 deer counted in the sampling areas, which equates to 111 deer per square mile for areas covered in the data collection.

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Overview. The number of a species that a given parcel of habitat can sustainably support over an extended period of time is defined as the "biological carrying capacity" or BCC. Deer reproduction can cause populations to exceed BCC. When BCC is exceeded, habitat quality decreases and herd health and physical conditions decline (McCullough 1979, McShea et al. 1997). Cultural carrying capacity is more relevant in urbanized settings and is the maximum number of deer that can coexist compatibly with local human populations.

All of the areas surveyed in this study have a deer density that is beyond the threshold of both biological and cultural carrying capacities, which has led to intolerable crop and landscape damage, intensified invasive flora and depleted forest habitat and the increased threat of automobile collisions and transmission of Lyme disease. Effective deer management aims for a deer population level that will allow the natural environment to thrive while striking an acceptable balance between people and deer.

Agriculture. Modern farming practices have caused crop yields to climb, aided by advances in improved crop varieties, herbicides, and fertilization methods. These superior plants containing added nutrients provide higher yields and excellent nutrition for New Jersey's growing deer herd at the expense of farmer profitability. In the late 1990s, Rutgers University conducted a study among the agricultural community due to rising losses in crop production because of deer damage. 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. 25% of responding farmers reported abandoning a parcel of tillable ground because of excessive damage and 36% of farmers have ceased growing their preferred crops as a result of excessive 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 (NJAES Center for Wildlife Damage 1998).

Due to an increase in member complaints regarding deer, New Jersey Farm Bureau conducted an informal survey of its farmer members in 2018 on deer-related losses. 36% of respondents reported annual crop damage of $10,000 or more, 11% claimed $25,000 in damage and 5% reported losses greater than $50,000. Most farmer respondents had altered their farming practices, some by planting less profitable crops and others by giving up fields entirely.

Agricultural damage has been reported in all the sampling areas in this report. A variety of non-lethal and lethal management techniques have consistently been implemented in all of the sampled areas but have not succeeded in reducing local deer populations to achieve economic viability for farmers.

Forest Ecology. Forest ecology suffers tremendously from deer over-browsing. Impacts to the forest understory start becoming deleterious when population densities surpass twenty deer per square mile, impeding upon forest regeneration (Drake et al. 2002). At densities greater than 100 per square mile, woodlands are void of understory from constant deer pressure through herbivory. Scientists and ecologists 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 as well as direct and indirect results of deer

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overabundance (Alverson et al. 1988). Insectivorous birds nesting on or near the ground such as oven birds and other neo-tropical migratory birds do not have 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, roots systems that hold soil in place are lessened 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 very difficult to implement with high deer densities.

Vehicular Accidents. 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 and many of the minor accidents do not even get reported. From October to December of 2016, AAA counted 4,463 reported deer-vehicle collisions in New Jersey (Flammia 2018).

According to new data by the National Insurance Crime Bureau, there were 16,905 claims for animal-caused losses filed by motorists in New Jersey last year (2017)—a 14.1 percent increase over the previous year (Sherman 2018).

Hillsborough Township, located in Somerset County, New Jersey, had the most reported vehicular accidents related to deer in 2017, making 316 insurance claims (Sherman 2018). The part of Hillsborough sampled in this report had a deer density minimum of 98 and maximum of 105 deer per square mile. Somerset County had a recent human fatality due to an unfortunate vehicular deer collision (Jennings 2017). Flemington, in Hunterdon County, had 202 incidents, and Monmouth County had over 851 claims (Sherman 2018). Passaic County suffered a recent fatality when a motorcyclist hit a deer in Wayne (Torrejon 2019).

Disease. 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 new data from the New Jersey Department of Health (Kent 2018). 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. When the deer density is greater than biological and/or cultural carrying capacity, the risk of disease increases for the deer as well (Cote et al. 2004).

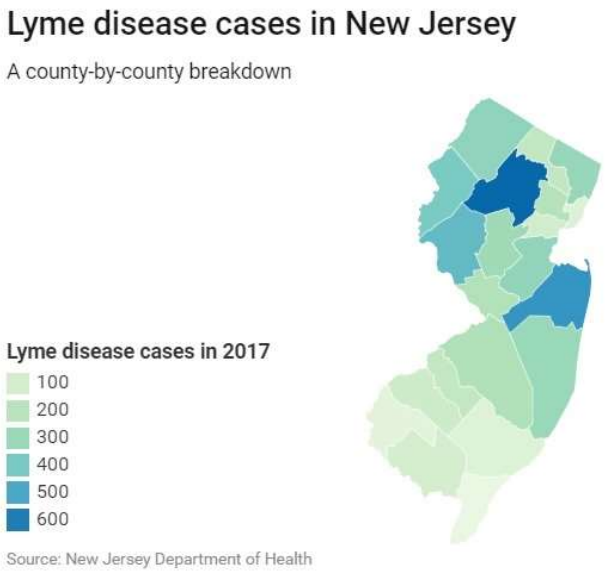

Figure 4. New Jersey Counties Lyme Cases in 2017

Open Space and Neighboring Properties. Male deer have a typical home range of one square mile (Diefenbach 2014). This can be affected by foraging habitat, cover and accessibility. New Jersey is fortunate to have many local, state and national parks, as well as preserved farmland, open space, conservation easements, wildlife management areas, game preserves, forest preserves, golf course, etc. However, these tracts of land become deer sanctuaries if not adequately managed, aiding in excessive population growth while harboring the species from effective hunting programs. 43% of respondents from the 1998 Rutgers deer 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. 50% of respondents in the same survey with intolerable losses indicated a refuge within a mile of their most severely affected fields. Most refuges were reported under private ownership, with publicly owned parcels causing problems in Monmouth, Mercer, Hunterdon and Burlington counties (NJAES Center for Wildlife Damage 1998).

Recommendations. The State of New Jersey needs to develop a Deer Management Plan similar to what's been published for the surrounding states. Local deer population goals need to be established throughout NJ so that deer density reduction goals may be devised based on the biological and cultural carrying capacities of each region. An environmental and economic assessment of the current deer overpopulation must be conducted in order to determine the CCC.

NJDEP community-based deer management programs should be encouraged through County Boards of Agriculture. There should be a state position for a Community-Based Deer Management Coordinator. Legislation should be passed to require all public lands to adequately manage the deer populations as well as all other wildlife. Legislation also needs to be supported to restrict the feeding but allow for baiting of deer. Those who harbor wildlife need to be held financially accountable for damage, perhaps through the issuance of citations and fines. Increasing deer harvest is absolutely essential. For example, simplification of NJ's deer zones, liberalization of the depredation process and use of crossbows, the issuance of "superpermits" and the ability to drive public lands and hunt with firearms on Sundays would all help to facilitate increased deer harvests.

A program to match agricultural landowners with recreational hunters should be considered in order to increase harvest pressure on farmlands experiencing deer damage to crops. Participating hunters would need to be safe, ethical and proficient at deer harvest. Venison should be donated through certified programs feeding the hungry in NJ, yet there needs to be funding to make that possible. Organizations like Hunters Helping the Hungry (HHH) only have funding for a very limited amount of deer to be processed, and funds have historically run out well before the season ends. In addition to funding, HHH needs more local butchers throughout the state to participate in the donation program.

Fencing can be effective in certain areas, yet also "pushes" the issue out to neighboring properties. The NJ State Agricultural Development Committee (SADC) currently has a deer-fencing program for preserved farmland. This program needs to be replicated by the NJ Department of Agriculture for farms that are not part of the preservation program. The NJDEP Green Acres program should develop a similar program to that of the SADC, where deer fencing grants could be made available to owners or farmers leasing preserved open space. In

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addition to a state program, USDA should consider amending their programs to include deer fencing as an eligible practice for cost-share grants.

A myriad of non-lethal deer damage management techniques are available, but have not been proven to be effective on a large scale. Deterrents use sound, visual, or tactile cues to frighten deer from areas where they are causing damage. Deterrents which are set off by the offending deer or those with irregular cues tend to me more effective since deer easily become acclimated to deterrents. Repellants use taste or scent to discourage deer from eating treated plants or entering treated areas. Repellants are expensive, require reapplication after rain events and may lose effectiveness at temperatures below freezing. Tests of fertility control in deer populations in fenced enclosures have demonstrated limited effectiveness. Currently, no fertility control agents for use in white-tailed deer are approved for use in New Jersey. If registered, future use of fertility control will have limited applicability, especially for large populations of free-ranging deer. Implementation of a fertility control program would be costly and herd reductions would still be necessary to reduce damage since fertility control does not directly reduce deer numbers.

Some form of commercial hunting must also be considered. Declines in hunter recruitment coupled with dramatic growth in numbers of white-tailed deer have challenged our ability to manage deer populations through regulated hunting. Regulated commercial harvest would help to reduce overabundant populations of deer; provide a source of healthy, natural, green, locally produced protein; promote economic growth, entrepreneurship, and market expansion; and public engagement and appreciation (Vercauteren 2011).

It is going to take stakeholder commitment to a combination of these recommendations in order to properly reduce New Jersey's deer herd to manageable levels.

-End of State Report-

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Appendix A

White-Tailed Deer (*Odocoileus virginiana*) Population Density Survey using sUAS Infrared; New Jersey Farm Bureau, Atlantic County

Study Area. Area sampled encompassed (5) mission areas totaling approximately 557 acres, almost 1 square mile, consisting of a mix of upland pineland woodland, agricultural fields (mostly vegetable crops), residential, fragmented woodland parcels, wetlands and minor open water. These areas were chosen because of their varied agricultural uses and the deer damage reported at County Board of Agriculture meetings. Neighboring areas are Egg Harbor City & Galloway Township. Bass River is to the north and Wharton State Forest to the northwest. *See Figures 1 and 2*.

Figure 1. **Atlantic County NJFB Deer Population Density Study State Orientation Map**

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Figure 2. **Atlantic County NJFB Deer Population Density Study Area**.

Process. Site reconnaissance included FAA mandatory daytime inspections of the project area to evaluate ingress/egress, potential launch/landing points, site hazards, obstructions, flight patterns, etc. High voltage electric lines and towers, cell phone and radio towers, water towers, severe changes in elevation, large trees, etc. Launch/landing sites were also pre-determined. *See Figure 3.*

Atlantic County study area required 11 missions the early morning of April 17, covering areas systematically, with one Pilot in Command (PIC), Visual Observer (VO), observer familiar with the land and small Unmanned Aerial Vehicles (sUAVs). Temperature on April 17th at 4am was 47° F with clear skies and waxing gibbous moon, providing excellent conditions to collect thermal data. Deciduous trees had not yet leafed out and evergreen tree coverage was moderate to heavy. Other heat signatures observed included boulders, field springs, pockets of water, streams, streetlights, active chimneys, drain inlets, electric transformers, cars in driveways, pets and other mammals.

Figure 3. **sUAS Launch/land coverage Map and Flight Plan for Atlantic County**.

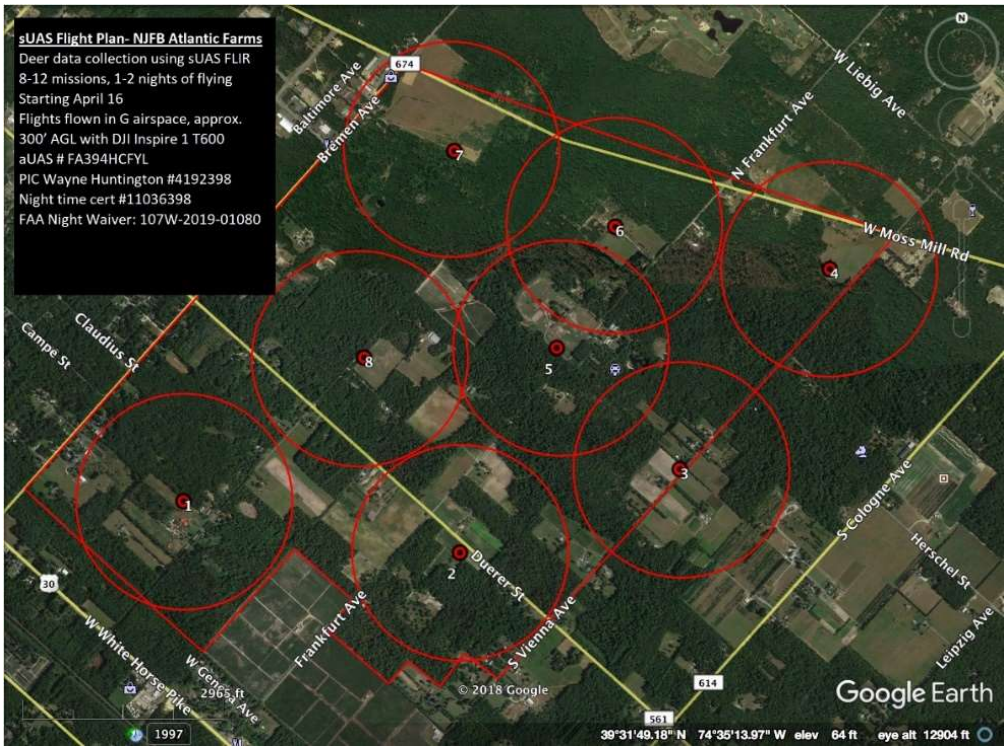

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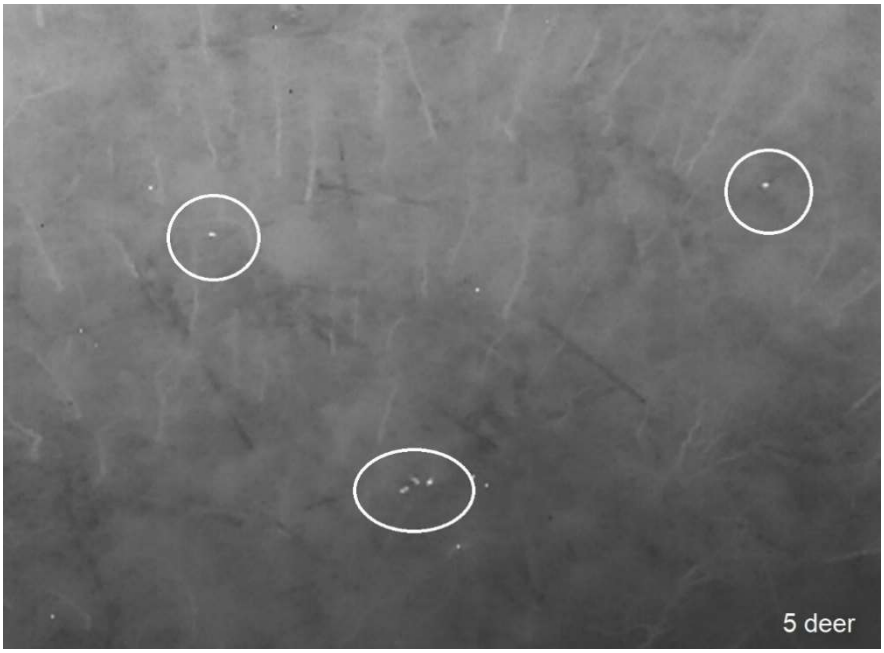
Figure 4. Thermal imagery example, NJFB Atlantic County



Images were collected using a Vertical Take-Off and Landing (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. We completed a quality saturation data collection of the project area, approximately 557 acres, almost one square mile. Deer heat signatures were visible and clear, contrasting with colder surroundings and demonstrating scale. *See Figures 4 and 5.*

Figure 5. Thermal imagery example, NJFB Atlantic County.

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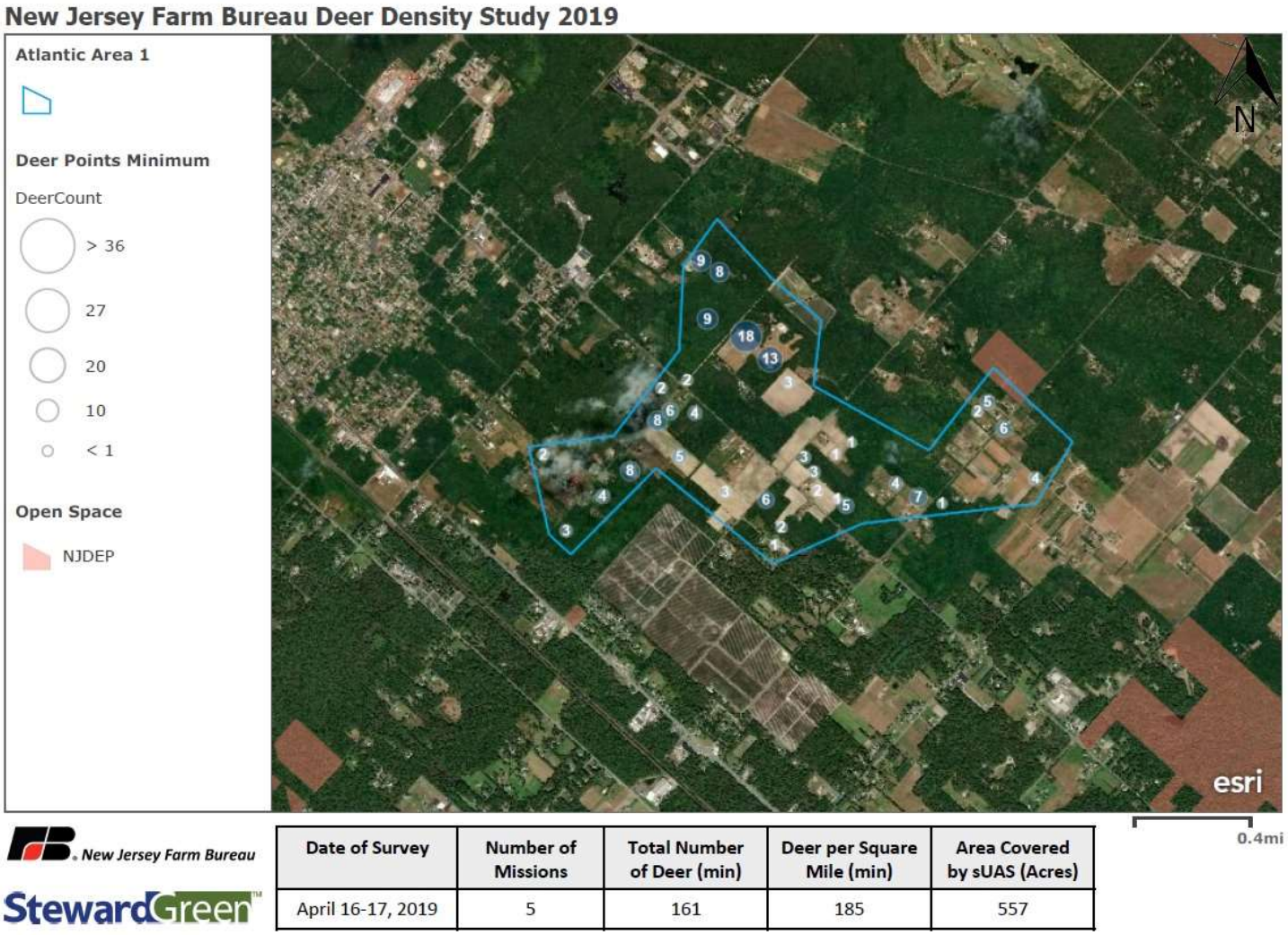
Results. At a minimum, there were 161 deer counted in the sampling area, which equates to 185 deer per square mile for area sampled in the data collection. At maximum, there were 169 deer counted in the sampling areas, which equates to 194 deer per square mile for area sampled in the data collection. *See Table 1 and Figures 6 and 7.*

Table 1. **Deer Density- Maximum vs. Minimum, Atlantic County, NJ**

Atlantic County:					
	Acres	Deer Max	Max SM	Deer mir	Min SM
Area 1	557	169	194	161	185

Figure 6. **Minimum Deer Density Map, Atlantic County, NJ**



Date of Survey	Number of Missions	Total Number of Deer (min)	Deer per Square Mile (min)	Area Covered by sUAS (Acres)
April 16-17, 2019	5	161	185	557

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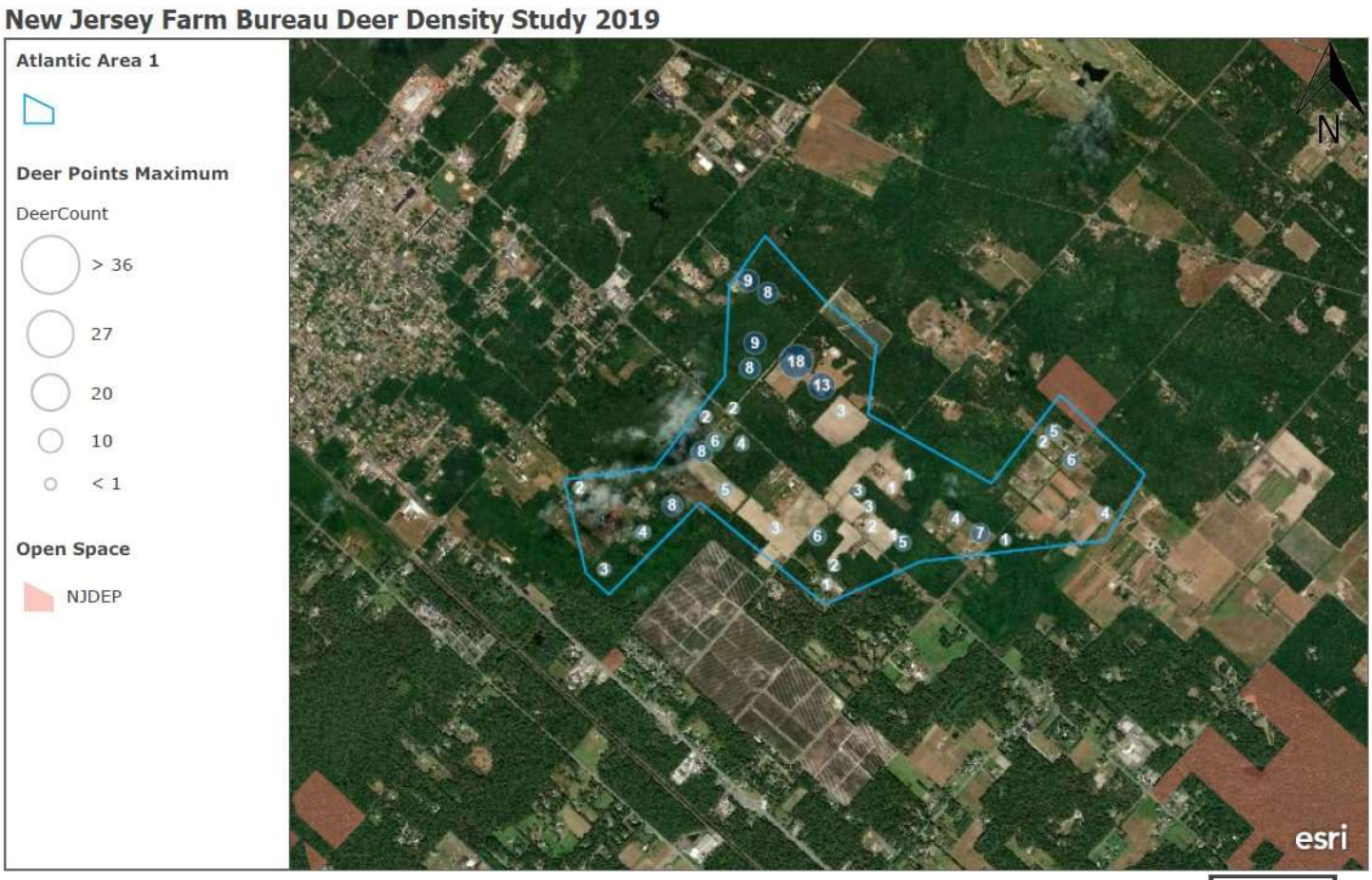
Figure 7. **Maximum Deer Density Map, Atlantic County, NJ**



Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 16-17, 2019	5	169	194	557

-End of Appendix A-

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Appendix B

White-Tailed Deer (*Odocoileus virginiana*) Population Density Survey using sUAS Infrared; New Jersey Farm Bureau, Cumberland County

Study Area. Areas sampled encompassed (3) study areas in Cumberland, Salem, Gloucester and Atlantic counties totaling approximately 1,520 acres or 2.4 square miles, consisting of a mix of upland woodland, agricultural fields (mostly vegetable crops), residential, fragmented woodland parcels, wetlands and minor open water. These areas were chosen because of their varied agricultural uses and the deer damage reported at County Board of Agriculture meetings. For simplicity, we will refer to the areas comprised in this chapter as "Cumberland". Surrounding towns include the city of Vineland, Buena Vista, Pittsgrove, Franklin and Millville. *See Figures 1, 2, 3 & 4*.

Figure 1. **Cumberland County NJFB Deer Population Density Study State Orientation Map**

Figure 2. **Cumberland County NJFB Deer Population Density Study Area 1 Northwest**.

Figure 3. **Cumberland County NJFB Deer Population Density Study Area 2 East**.

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Figure 4. **Cumberland County NJFB Deer Population Density Study Area 3 South**.

Process. Site reconnaissance included FAA mandatory daytime inspections of the project area to evaluate ingress/egress, potential launch/landing points, site hazards, obstructions, flight patterns, etc. High voltage electric lines and towers, cell phone and radio towers, water towers, severe changes in elevation, large trees, etc. Launch/landing sites were also pre-determined. *See Figure 4.*

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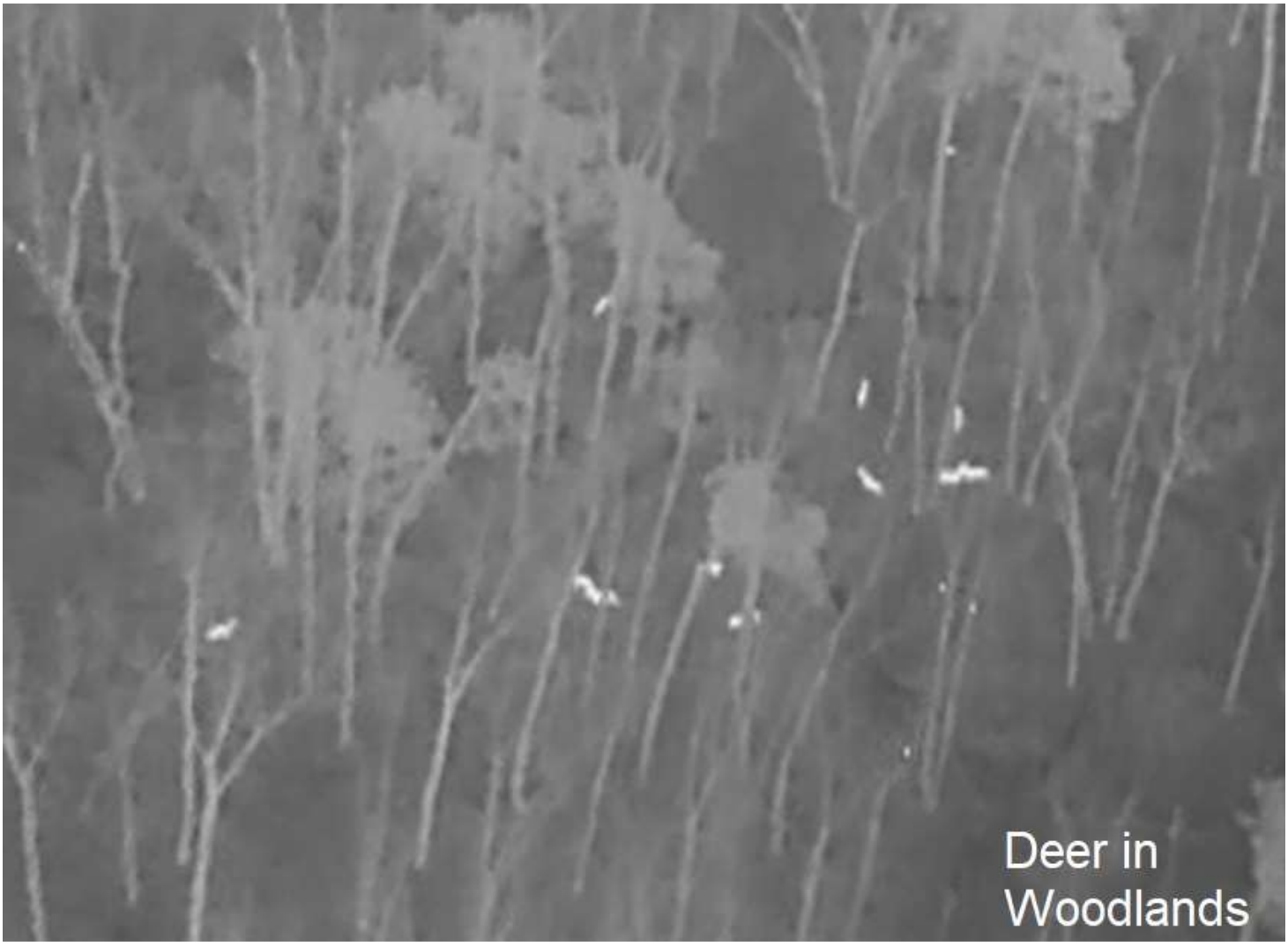
Figure 4. **sUAS Launch/land coverage Map and Flight Plan for Cumberland County**.

Cumberland County study areas required 11 missions the nights of early mornings of April 16-17, covering areas systematically, with one Pilot in Command (PIC), Visual Observer (VO), observer familiar with the land and small Unmanned Aerial Vehicles (sUAVs). Temperature on April 17th at 1 am was 49° F with clear skies and waxing gibbous moon, providing excellent conditions to collect thermal data. Deciduous trees had not yet leafed out and evergreen tree coverage was minimal. Other heat signatures observed included boulders, field springs, pockets of water, streams, streetlights, active chimneys, drain inlets, electric transformers, cars in driveways, pets and other mammals.

Figure 5. Thermal imagery example, NJFB Cumberland County; Area 2 East



Images were collected using a Vertical Take-Off and Landing (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. We completed a quality saturation data collection of all project areas flown, approximately 1,520 acres or 2.4 square miles. The Cumberland County sampling was represented by 3 areas; Area 1 Northwest, Area 2 East and Area 3 South. These areas were then broken into smaller units due to coverage capability. Deer heat signatures were visible and clear, contrasting with colder surroundings and demonstrating scale. See *Figures 5 and 6.*

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Figure 6. Thermal imagery example, NJFB Cumberland County, Areas 1, 2 & 3.

Results. At a minimum, there were 245 deer counted in the sampling areas, which equates to 103 deer per square mile for areas sampled in the data collection. At maximum, there were 255 deer counted in the sampling areas, which equates to 107 deer per square mile for areas sampled in the data collection. *See Figures 7,8, 9, 10 and 11 and Table 1.*

Table 1. **Deer Density- Maximum vs. Minimum, Cumberland County, NJ**

Cumberland County:					
	Acres	Deer Max	Max SM	Deer mir	Min SM
Area 1 Northwest	707	76	69	75	68
Area 2 East	345	115	213	112	208
Area 3 South	468	64	88	58	79
Totals:	1520	255	107	245	103

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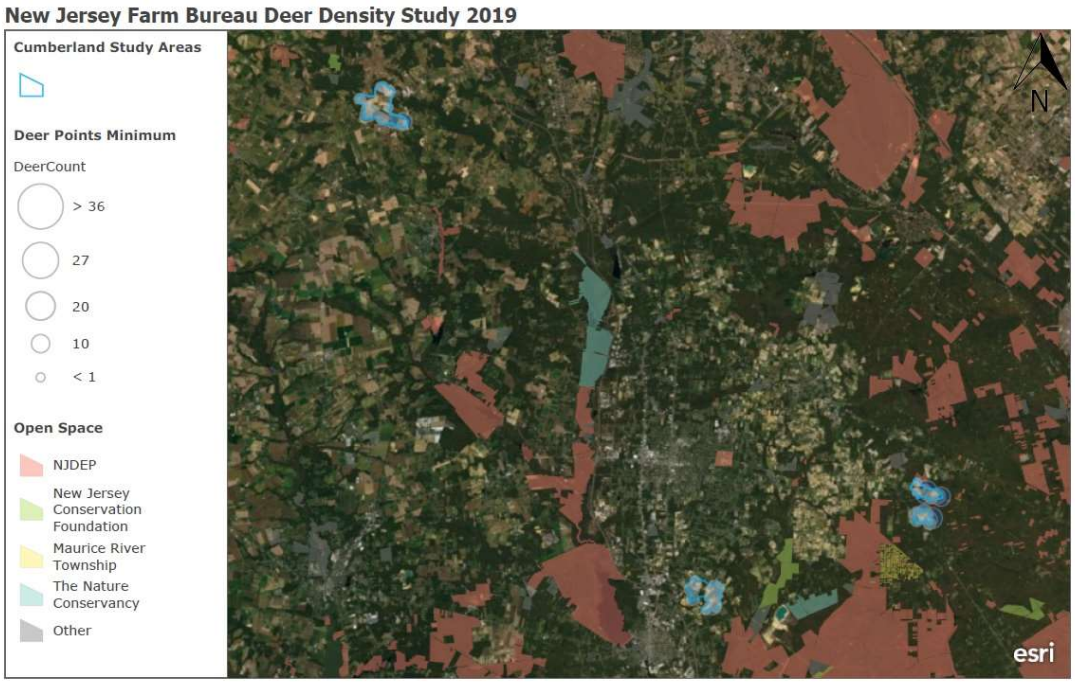
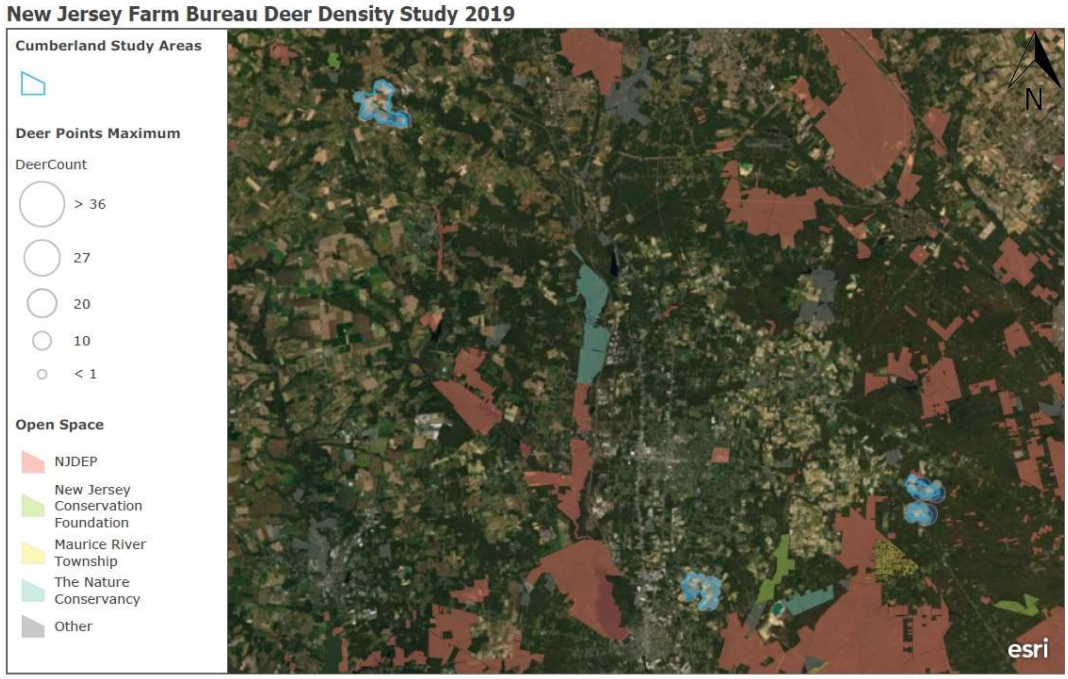
Figure 7. **Minimum Deer Density Map, Cumberland County, NJ**



Date of Survey	Number of Missions	Total Number of Deer (min)	Deer per Square Mile (min)	Area Covered by sUAS (Acres)
April 16-17, 2019	11	245	103	1,520

Earthstar Geographics

Figure 8. **Maximum Deer Density Map, Cumberland County, NJ**



Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 16-17, 2019	11	255	107	1,520

Earthstar Geographics

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Figure 9. **Deer Density Maps Area 1 Northwest, Cumberland**

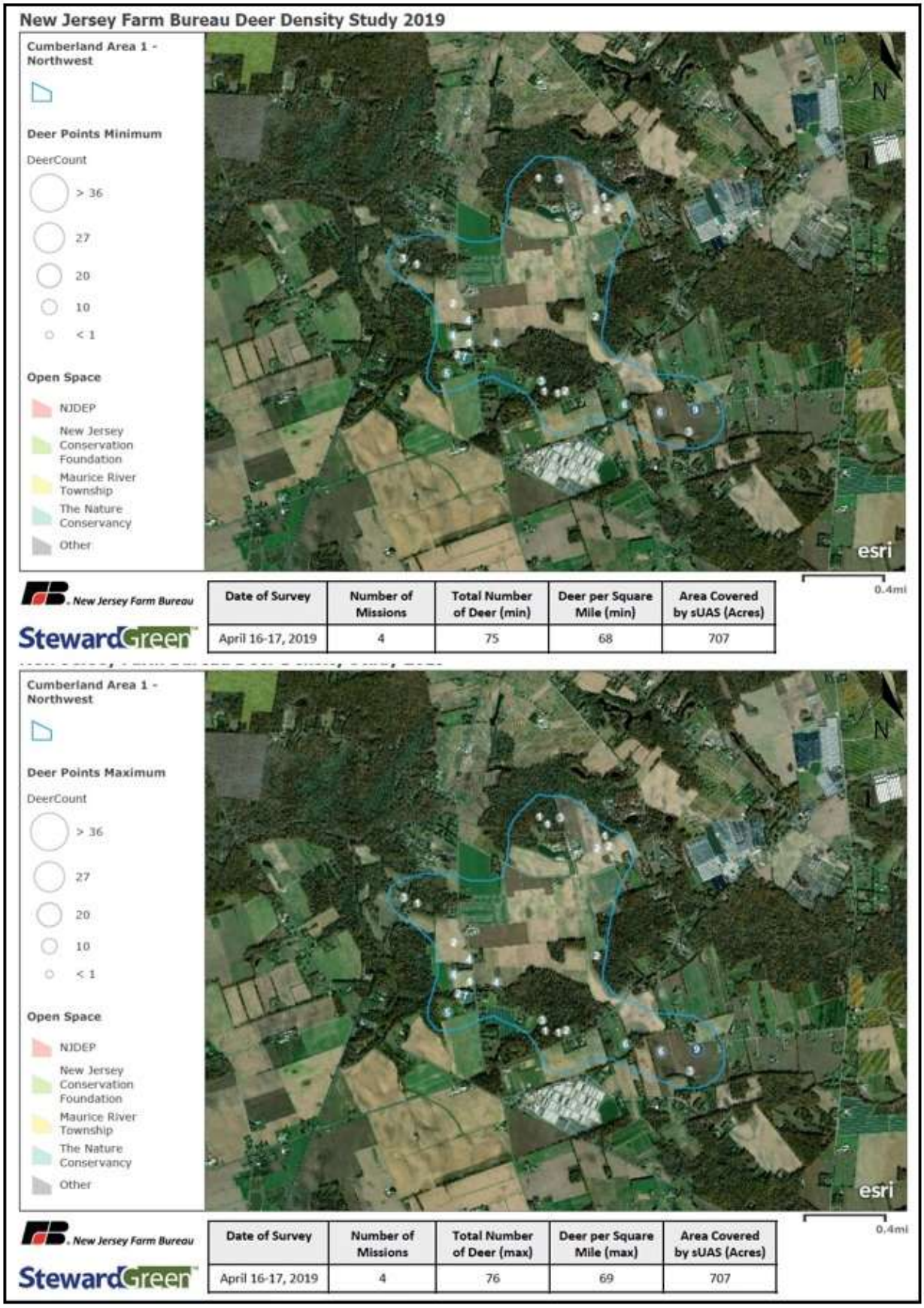
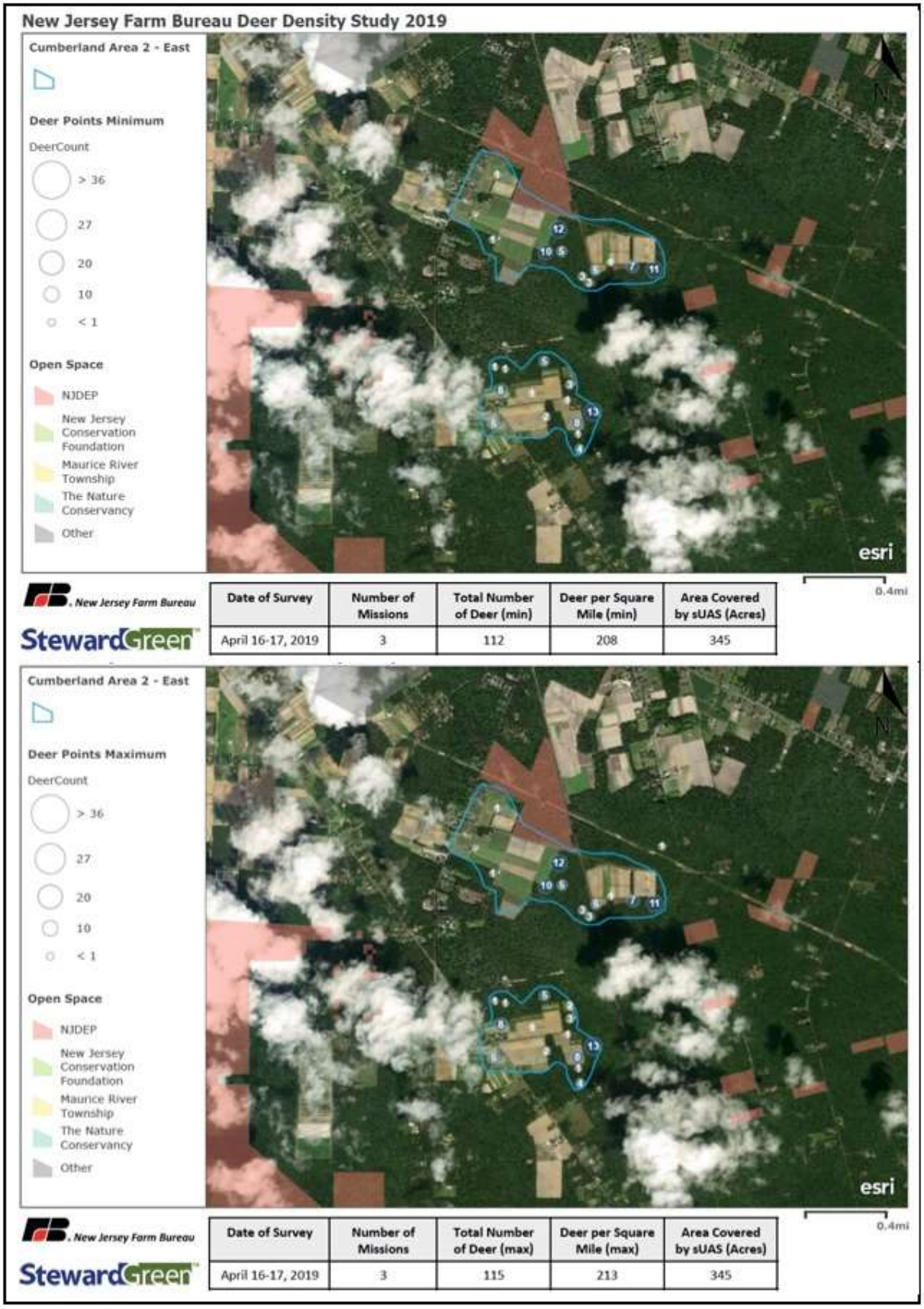


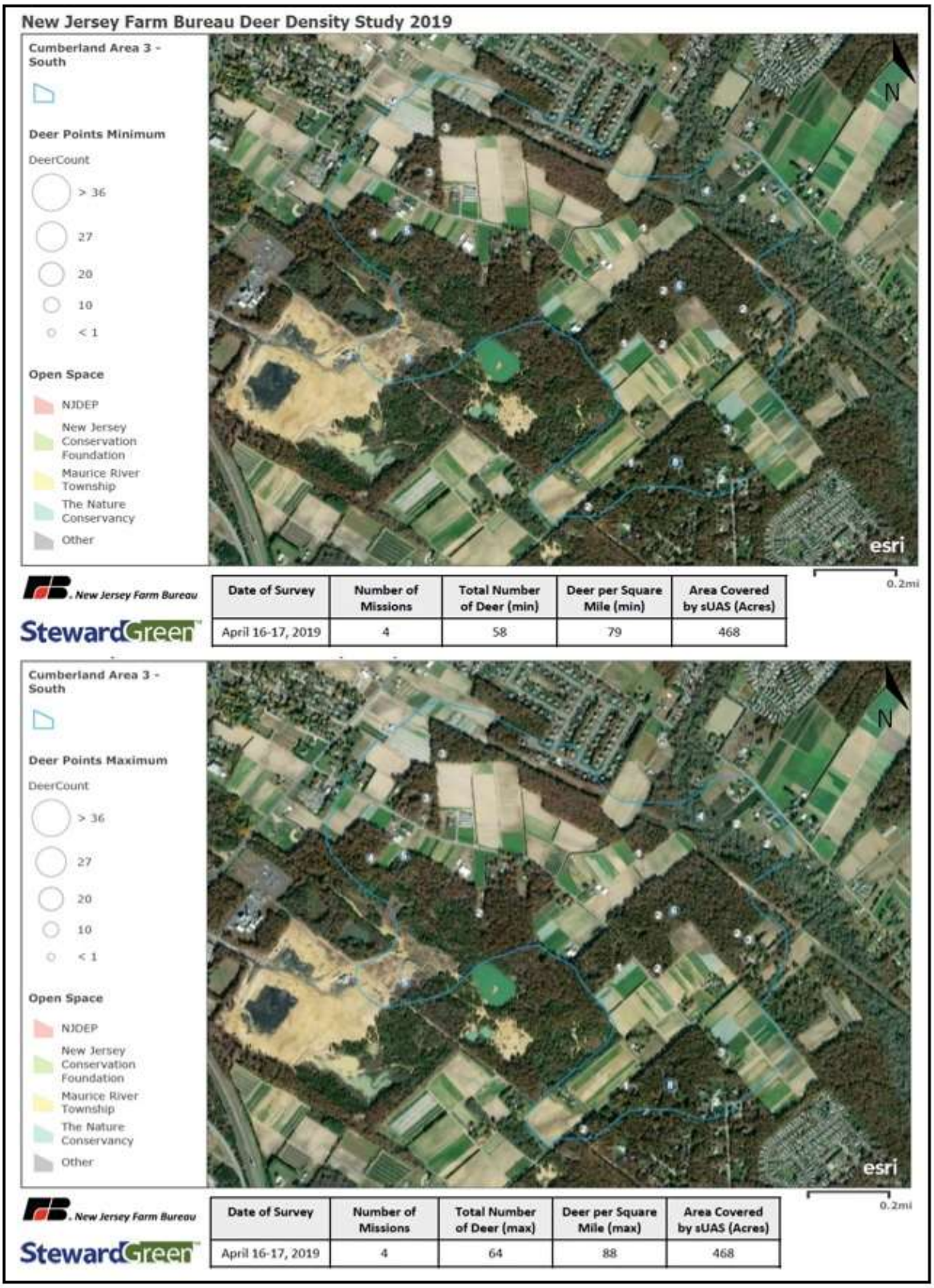
Figure 10. **Deer Density Maps Area 2 East, Cumberland**



Date of Survey	Number of Missions	Total Number of Deer (min)	Deer per Square Mile (min)	Area Covered by sUAS (Acres)
April 16-17, 2019	3	112	208	345

Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 16-17, 2019	3	115	213	345

Figure 11. **Maximum Deer Density Maps Area 3, South**



Date of Survey	Number of Missions	Total Number of Deer (min)	Deer per Square Mile (min)	Area Covered by sUAS (Acres)
April 16-17, 2019	4	58	79	468

Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 16-17, 2019	4	64	88	468

-End of Appendix B-

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Appendix C

White-Tailed Deer (*Odocoileus virginiana*) Population Density Survey using sUAS Infrared; New Jersey Farm Bureau, Hunterdon County

Study Area. Areas sampled encompassed (3) study areas totaling approximately 1,659 acres or 2.6 square miles, consisting of a mix of upland woodland, agricultural fields, residential, fragmented woodland parcels, wetlands and minor open water. These areas were chosen because of their varied agricultural uses and the deer damage reported at County Board of Agriculture meetings. Neighboring towns include Hopewell, Pennington, Lambertville, East & West Amwell and Ringoes. Stony Brook, The Watershed Institute, St. Michael's Farm Preserve, Skyview Preserve, Sourland Mountain Preserve, Washington Crossing Park and the Delaware River are all in the vicinity. *See Figures 1 and 2*.

Figure 1. **Hunterdon County NJFB Deer Population Density Study State Orientation Map**

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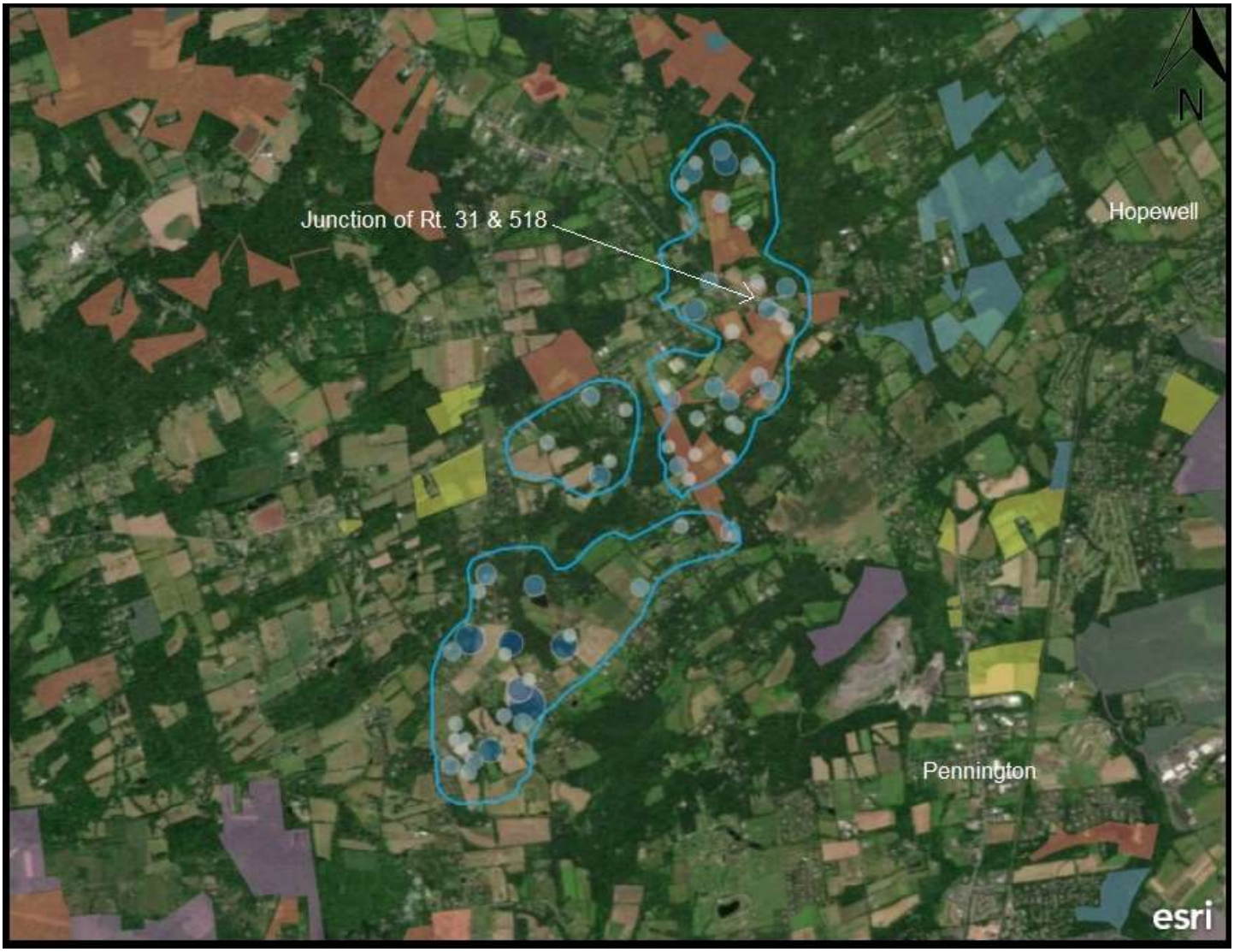
Figure 2. **Hunterdon County NJFB Deer Population Density Study Area 1 Northeast, Area 2 West and Area 3 South**.



Process. Site reconnaissance included FAA mandatory daytime inspections of the project area to evaluate ingress/egress, potential launch/landing points, site hazards, obstructions, flight patterns, etc. High voltage electric lines and towers, cell phone and radio towers, water towers, severe changes in elevation, large trees, etc. Launch/landing sites were also pre-determined. *See Figure 3.*

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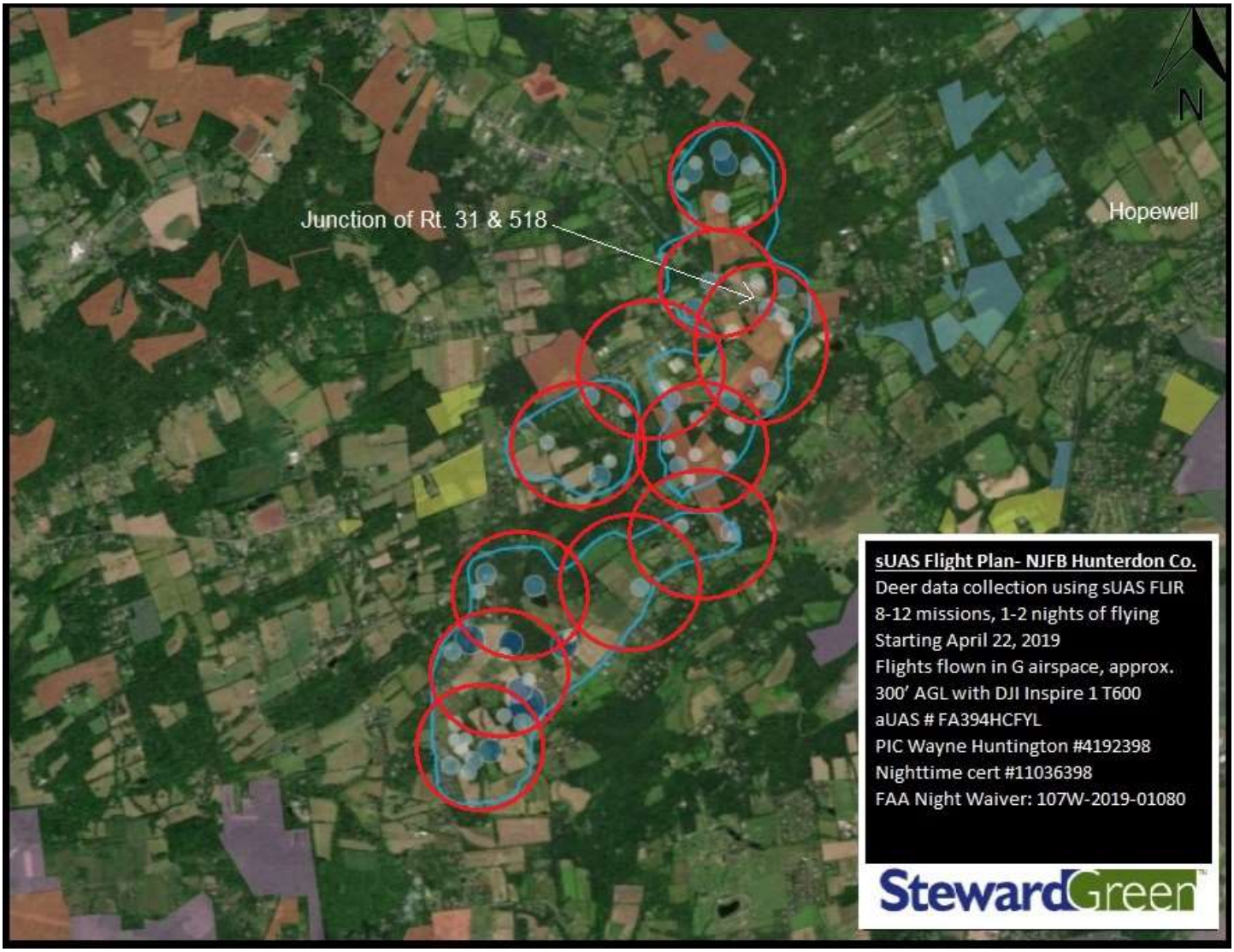
Figure 3. **sUAS Launch/land coverage Map and Flight Plan for Hunterdon County**.



The Hunterdon/Mercer County study areas required 11 missions the nights of early mornings of April 27 & 28, covering areas systematically, with one Pilot in Command (PIC), Visual Observer (VO), observer familiar with the land and small Unmanned Aerial Vehicles (sUAVs). Temperature on April 28th at 1am was 42° F with partly cloudy skies and last quarter moon, providing excellent conditions to collect thermal. Deciduous trees had not yet leafed out completely and evergreen tree coverage was minimal. Other heat signatures observed included boulders, field springs, pockets of water, streams, streetlights, active chimneys, drain inlets, electric transformers, cars in driveways, pets and other mammals.

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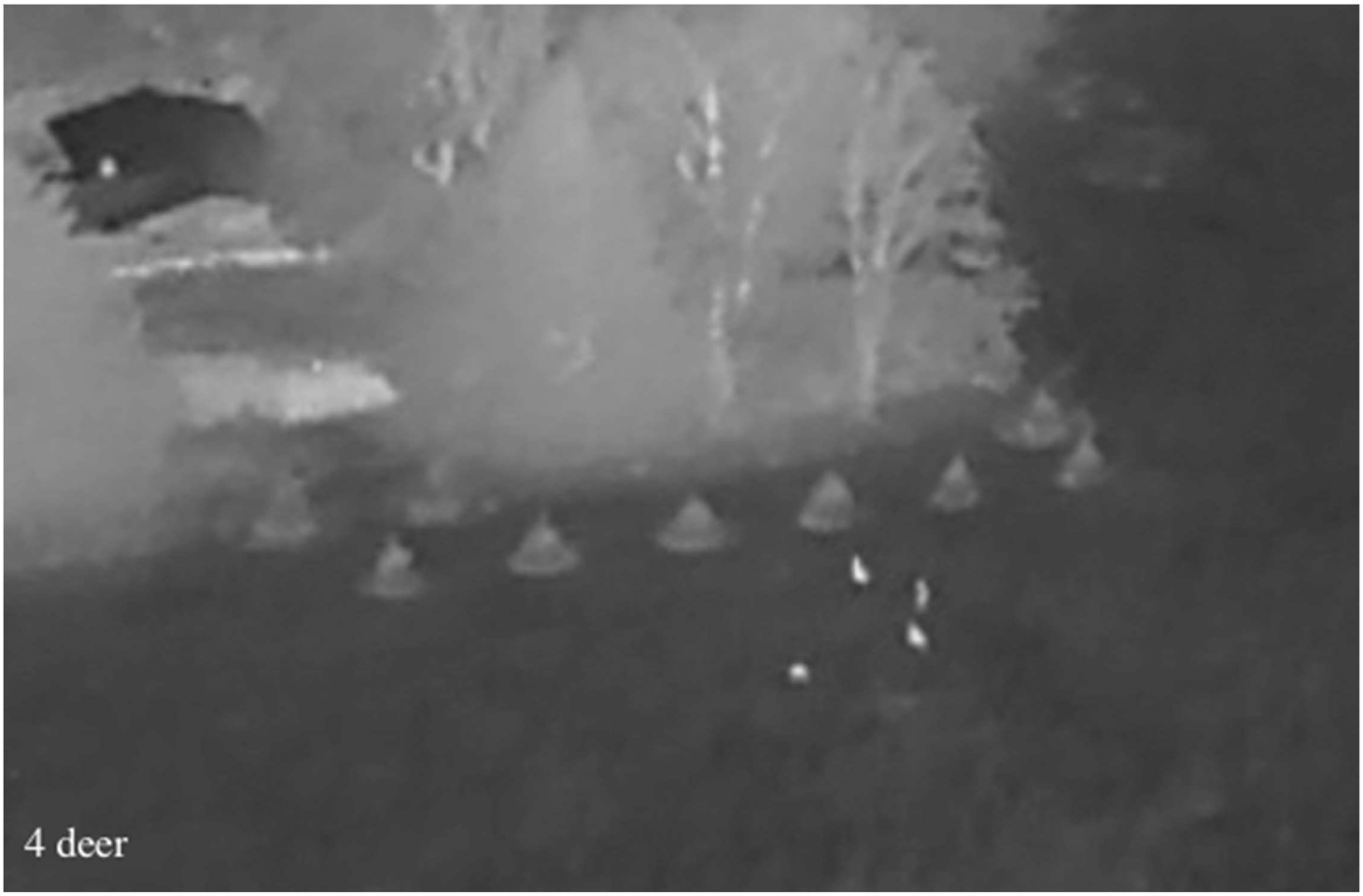
Figure 4. Thermal imagery example, NJFB Hunterdon County



Images were collected using a Vertical Take-Off and Landing (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. We completed a quality saturation data collection of all project areas flown, approximately 1,693 acres or 2.6 square miles. The Hunterdon County samplings were represented by 3 areas; Area 1 Northeast, Area 2 West and Area 3 Southwest. These areas were then broken into smaller areas due to coverage capability. Deer heat signatures were visible and clear, contrasting with colder surroundings and demonstrating scale. *See Figures 4 and 5.*

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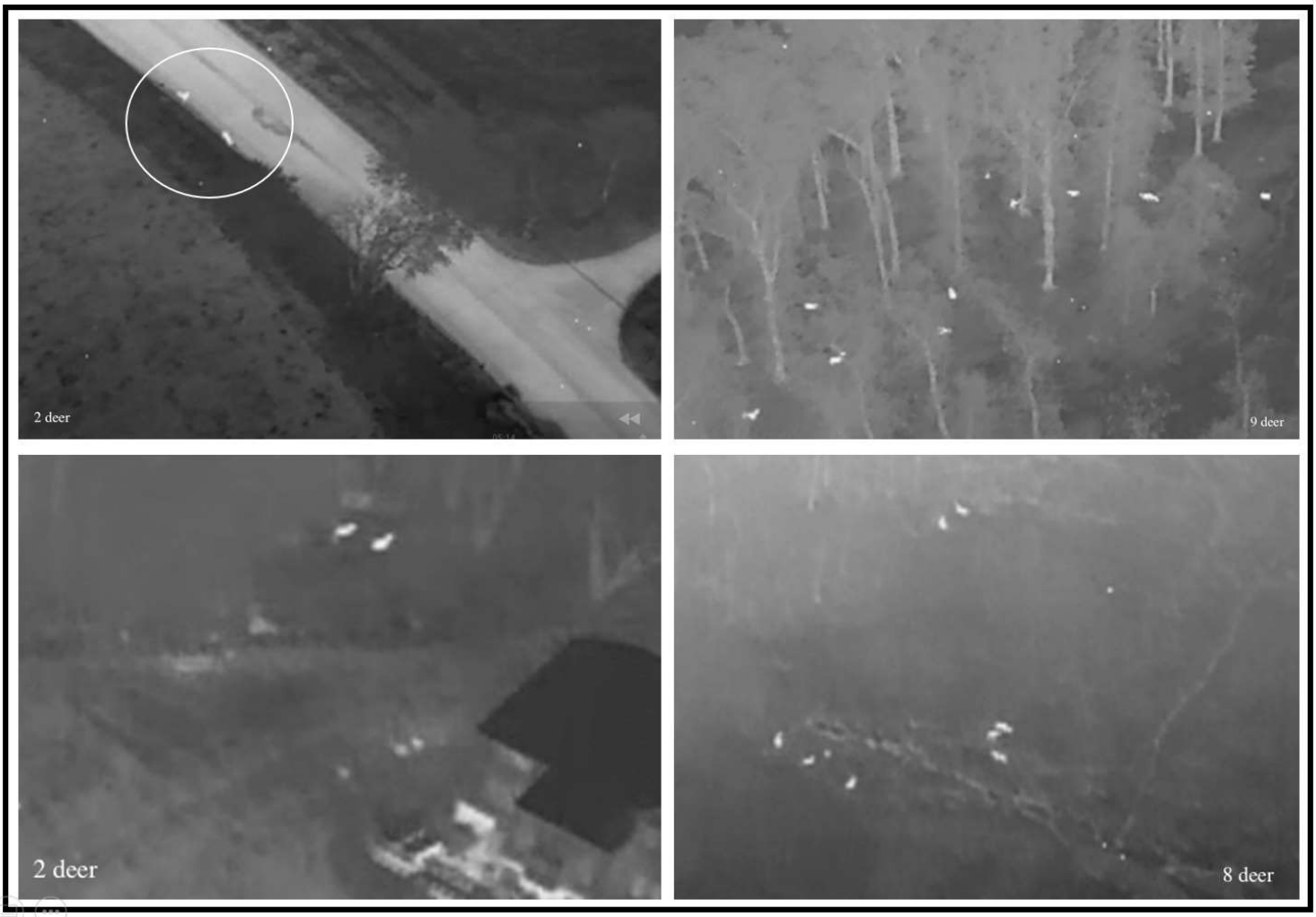
Figure 5. Thermal imagery examples, NJFB Hunterdon County.



Results. At a minimum, there were 230 deer counted in the sampling areas, which equates to 89 deer per square mile for areas sampled in the data collection. At maximum, there were 231 deer counted in the sampling areas, which equates to 89 deer per square mile for areas sampled in the data collection. *See Figures 6,7, 8, 9, 10 and Table 1.*

Table 1. **Deer Density- Maximum vs. Minimum, Hunterdon County, NJ**

Hunterdon/Mercer County:					
	Acres	Deer Max	Max SM	Deer mir	Min SM
Area 1 Northeast	691	97	90	96	89
Area 2 West	207	14	43	14	43
Area 3 Southwest	761	120	101	120	101
Totals:	1659	231	89	230	89

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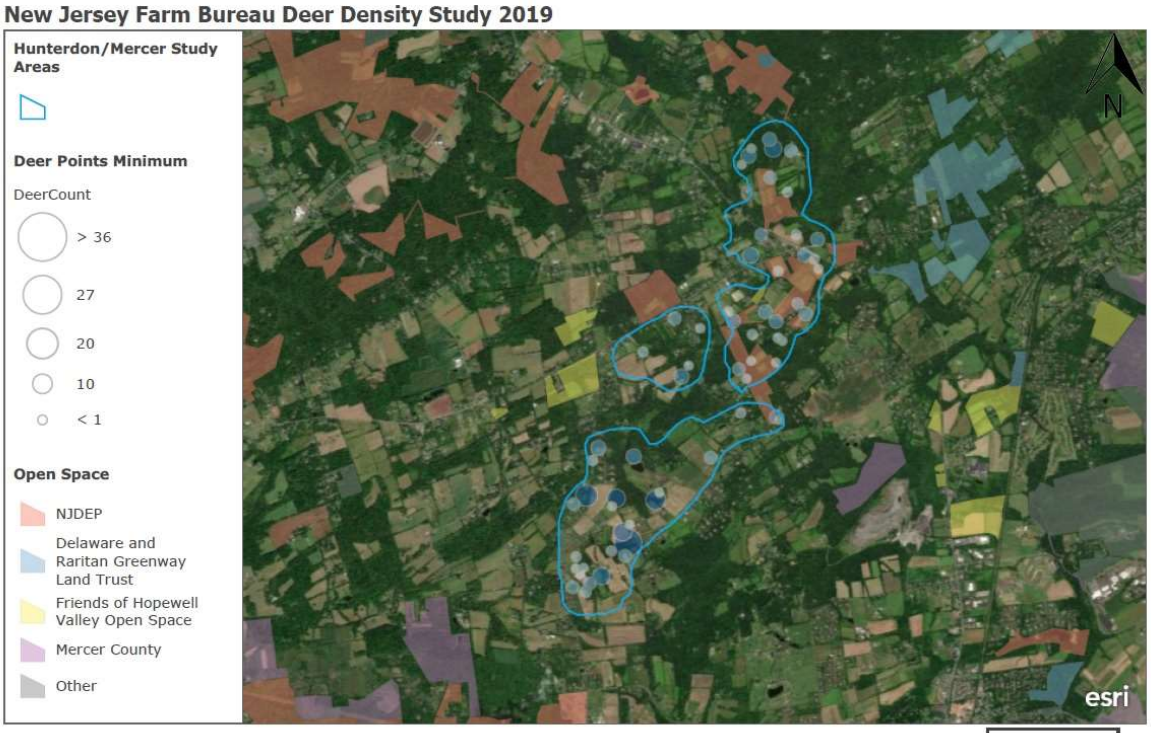
Figure 6. **Minimum Deer Density Map, Hunterdon County, NJ**



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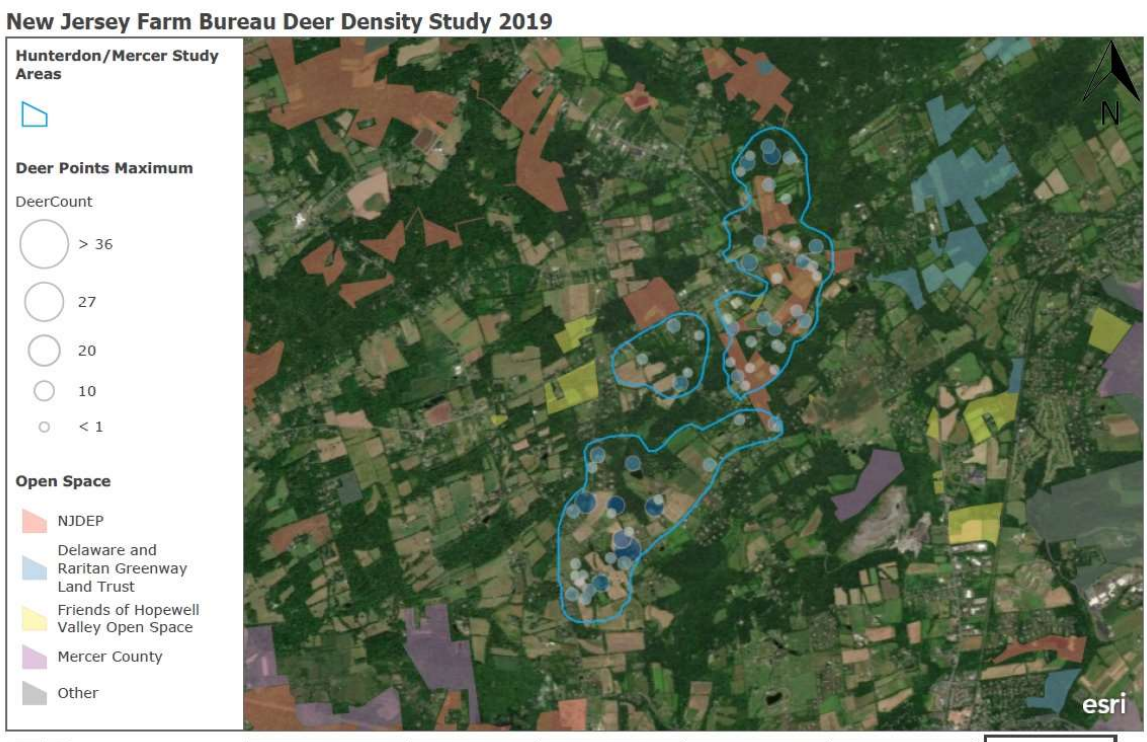
Date of Survey	Number of Missions	Total Number of Deer (min)	Deer per Square Mile (min)	Area Covered by sUAS (Acres)
April 27-28, 2019	11	230	89	1,659

Figure 7. **Maximum Deer Density Map, Hunterdon County, NJ**

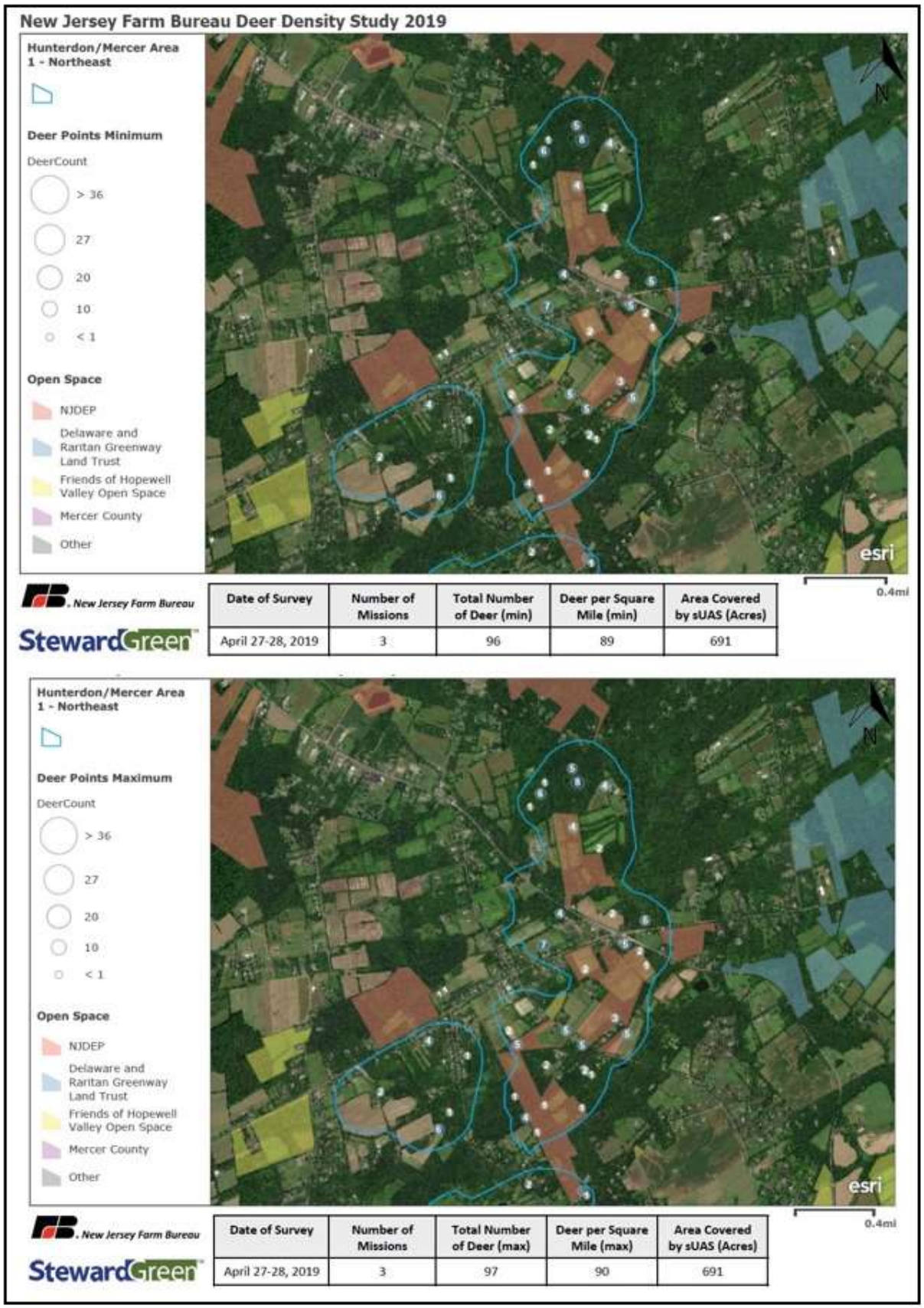


New Jersey Farm Bureau

StewardGreen™

Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 27-28, 2019	11	231	89	1,659

Figure 8. **Deer Density Maps Area 1 Northeast**



Date of Survey	Number of Missions	Total Number of Deer (min)	Deer per Square Mile (min)	Area Covered by sUAS (Acres)
April 27-28, 2019	3	96	89	691

Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 27-28, 2019	3	97	90	691

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Figure 9. **Deer Density Maps Area 2 West**

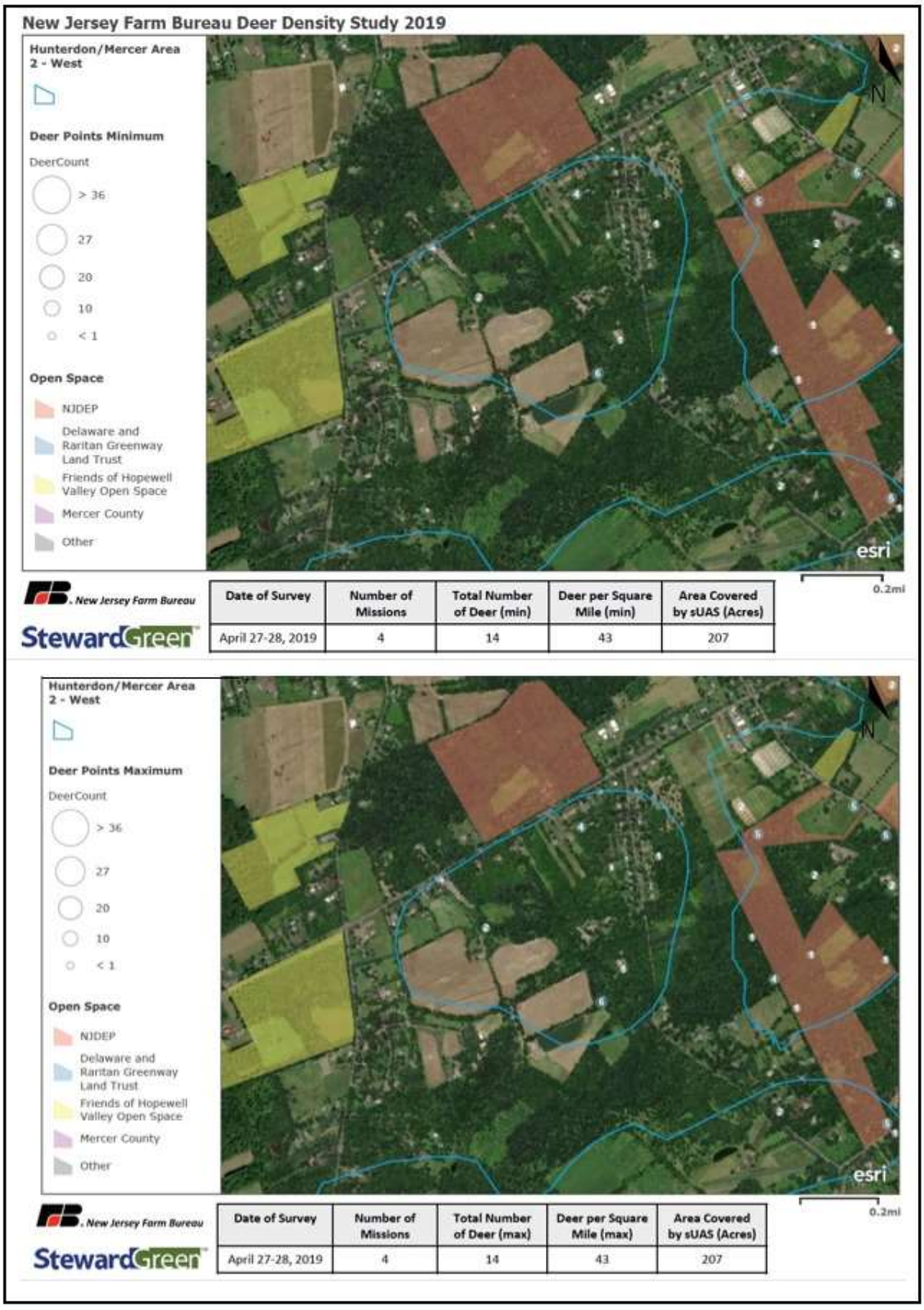
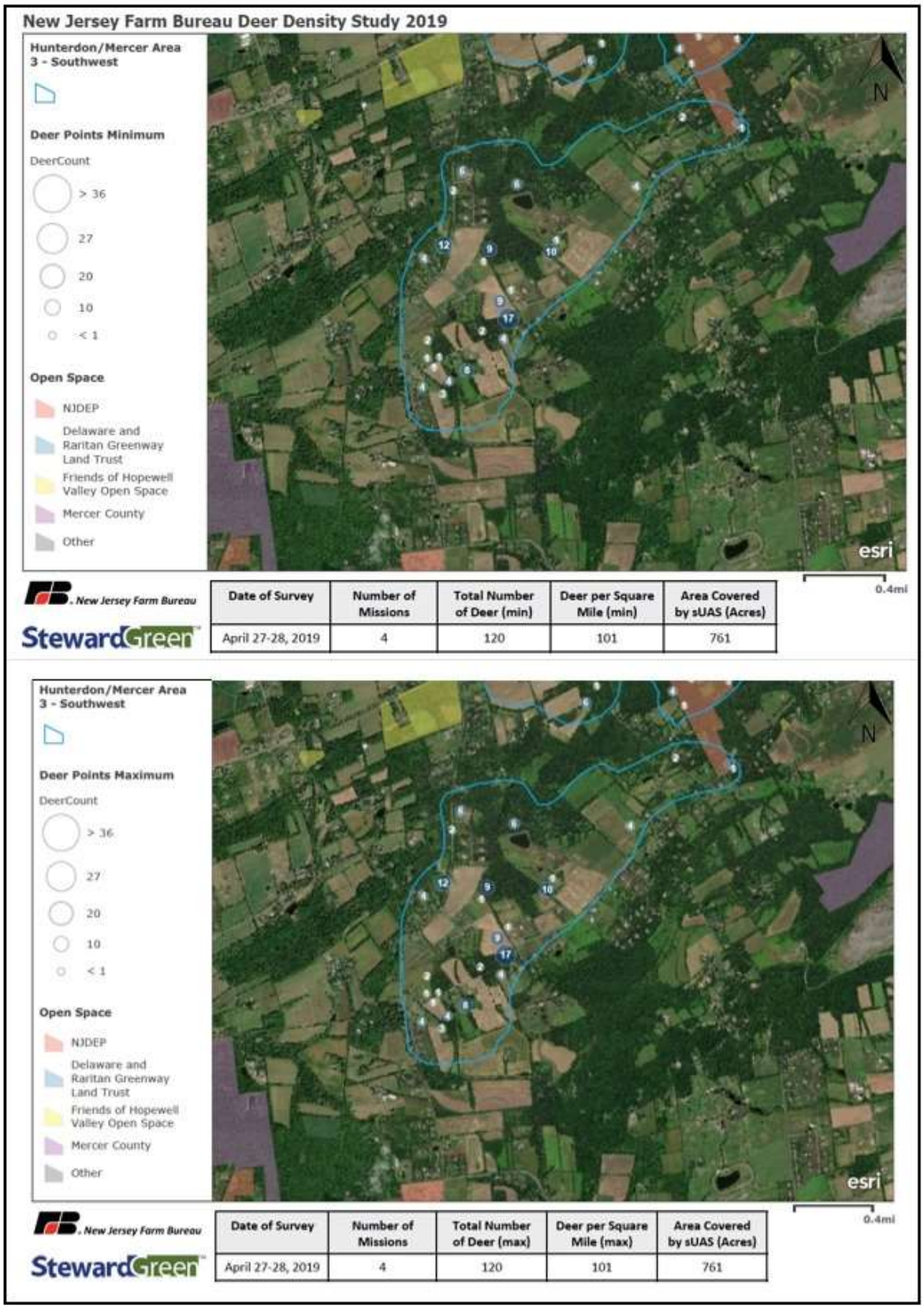


Figure 10. **Deer Density Maps Area 3, Southwest**



-End of Appendix C-

Appendix D

White-Tailed Deer (*Odocoileus virginiana*) Population Density Survey using sUAS Infrared; New Jersey Farm Bureau, Monmouth County

Study Area. Areas sampled encompassed (3) study areas totaling approximately 3,390 acres or 5.3 square miles, consisting of a mix of upland woodland, agricultural fields, residential, fragmented woodland parcels, wetlands and minor open water. These areas were chosen because of their varied agricultural uses and the deer damage reported at County Board of Agriculture meetings. Neighboring towns are Millstone, Roosevelt and Clarksburg. Six Flags Great Adventure, Assunpink Wildlife Management Area, Perrineville Lake Park, Turkey Swamp Park and Colliers Mills Wildlife Management Area are in the general area. *See Figures 1 and 2*.

Figure 1. **Monmouth County NJFB Deer Population Density Study State Orientation Map**

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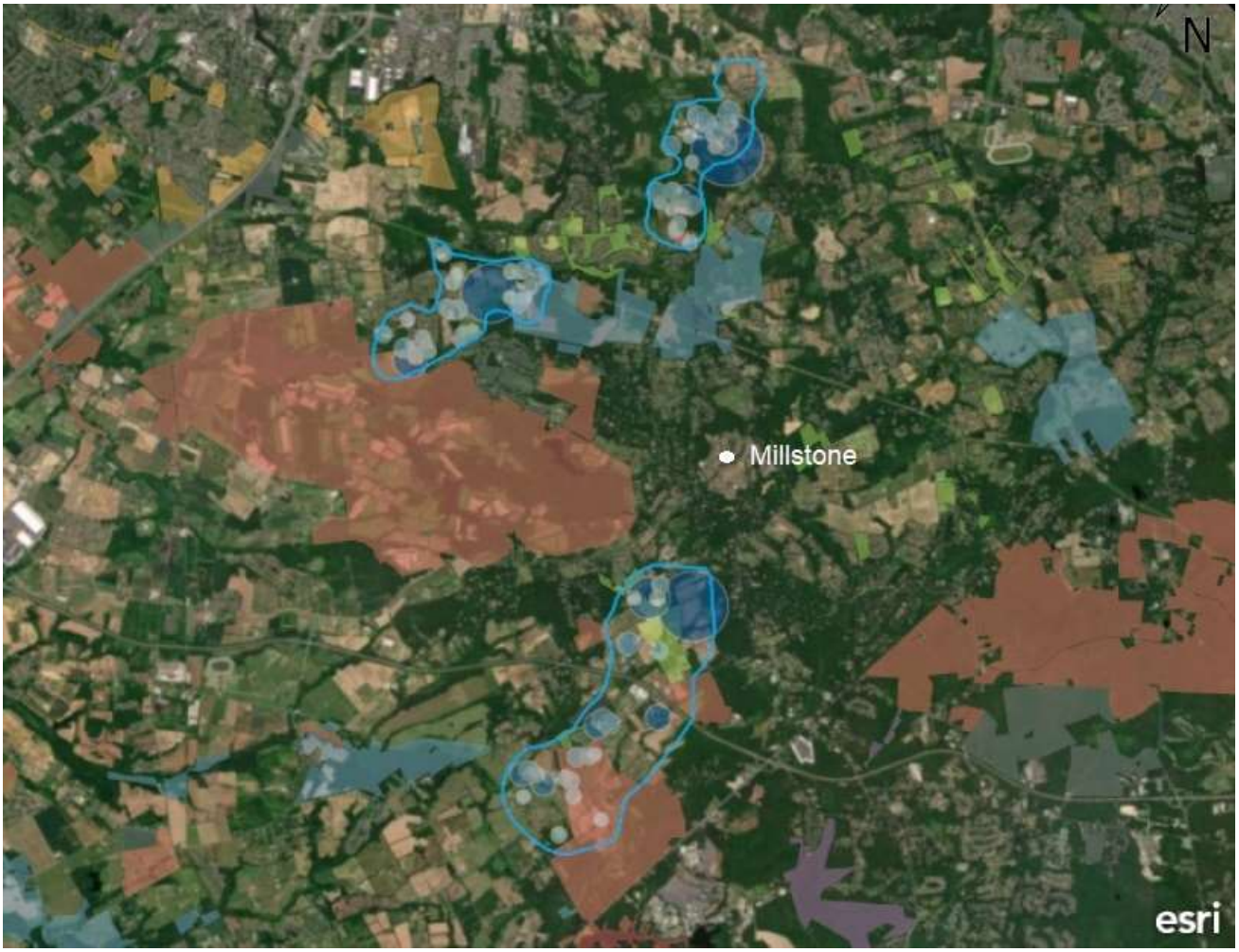
Figure 2. **Monmouth County NJFB Deer Population Density Study Area 1 Northeast, Area 2 West and Area 3 South**.



Process. Site reconnaissance included FAA mandatory daytime inspections of the project area to evaluate ingress/egress, potential launch/landing points, site hazards, obstructions, flight patterns, etc. High voltage electric lines and towers, cell phone and radio towers, water towers, severe changes in elevation, large trees, etc. Launch/landing sites were also pre-determined. *See Figure 3.*

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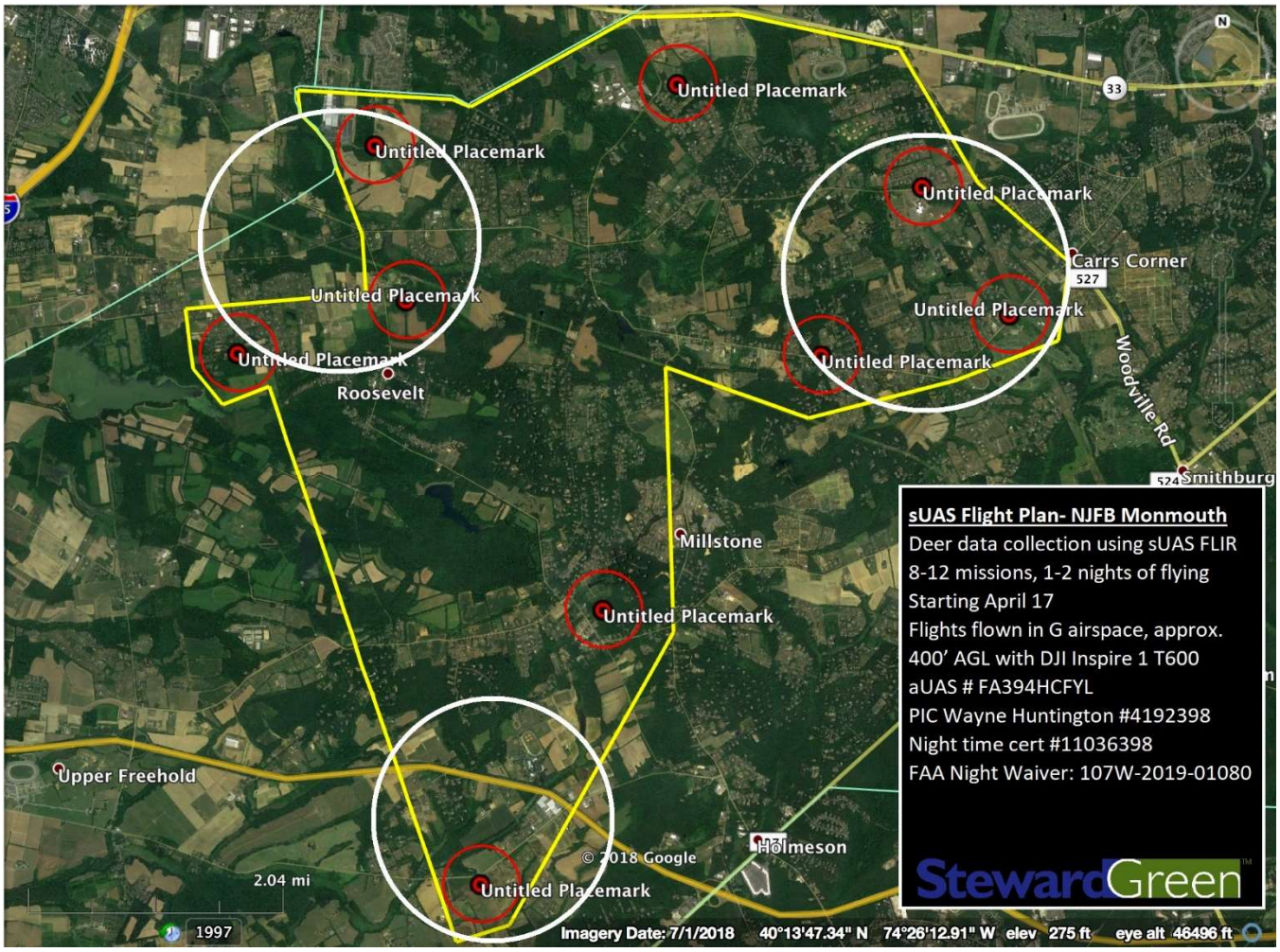
Figure 3. **sUAS Launch/land coverage Map and Flight Plan for Monmouth County**.



The Monmouth County study areas required 9 missions the nights of early mornings of April 17-18, covering areas systematically, with one Pilot in Command (PIC), Visual Observer (VO), observer familiar with the land and small Unmanned Aerial Vehicles (sUAVs). Temperature on April 18th at 1am was 51° F with partly cloudy skies and waxing gibbous moon, providing excellent conditions to collect thermal data. Deciduous trees had not yet leafed out and evergreen tree coverage was minimal. Other heat signatures observed included boulders, field springs, pockets of water, streams, streetlights, active chimneys, drain inlets, electric transformers, cars in driveways, pets and other mammals.

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Figure 4. Thermal imagery example, NJFB Monmouth County

Images were collected using a Vertical Take-Off and Landing (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. We completed a quality saturation data collection of all project areas flown, approximately 3,390 acres, about 5.3 square miles. The Cumberland County samplings were represented by 3 areas; Area 1 Northeast, Area 2 West and Area 3 South. These areas were then broken into smaller areas due to coverage capability. Deer heat signatures were visible and clear, contrasting with colder surroundings and demonstrating scale. *See Figures 4 and 5.*

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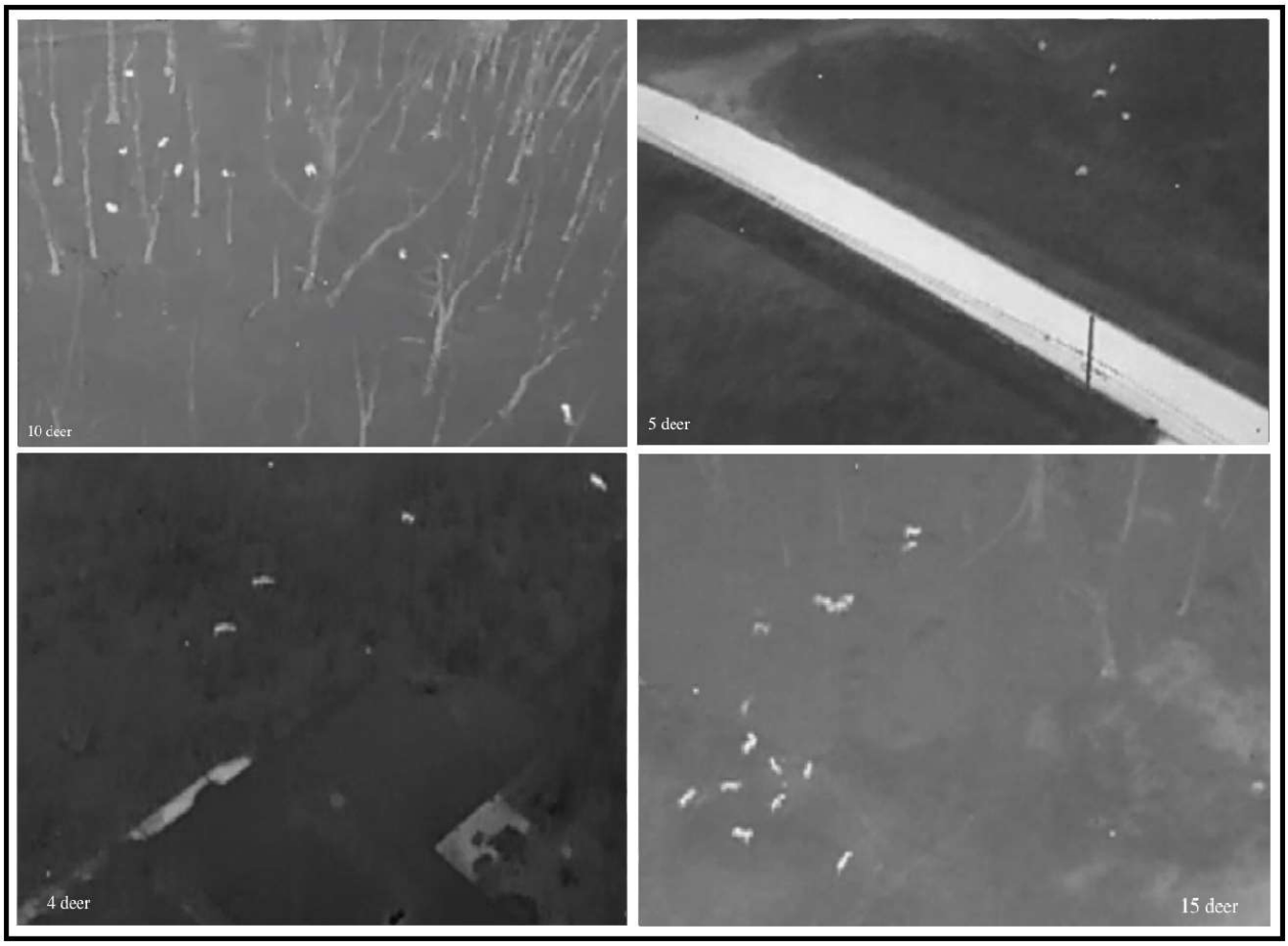
Figure 5. Thermal imagery examples, NJFB Monmouth County.



Results. At a minimum, there were 344 deer counted in the sampling areas, which equates to 65 deer per square mile for areas sampled in the data collection. At maximum, there were 350 deer counted in the sampling areas, which equates to 66 deer per square mile for areas sampled in the data collection. *See Figures 6, 7, 8, 9, 10 and Table 1.*

Table 1. **Deer Density- Maximum vs. Minimum, Monmouth County, NJ**

Monmouth County:					
	Acres	Deer Max	Max SM	Deer mir	Min SM
Area 1 Northeast	757	96	81	92	78
Area 2 West	681	121	114	121	114
Area 3 South	1952	133	44	131	43
Totals:	3390	350	66	344	65

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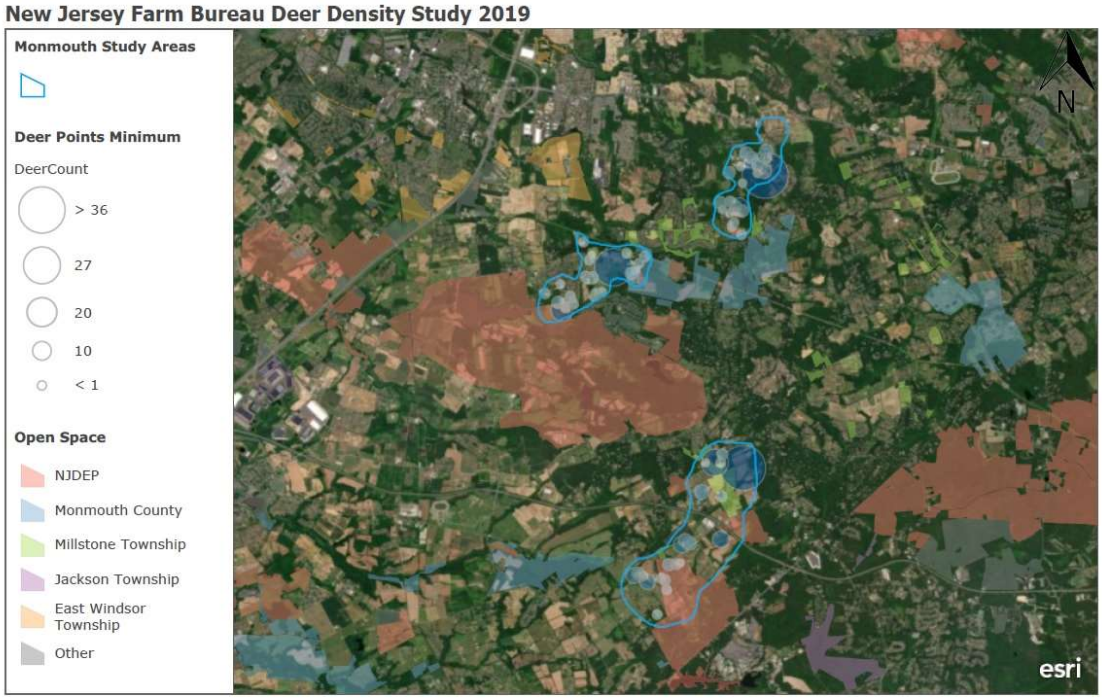
Figure 6. **Minimum Deer Density Map, Monmouth County, NJ**



New Jersey Farm Bureau

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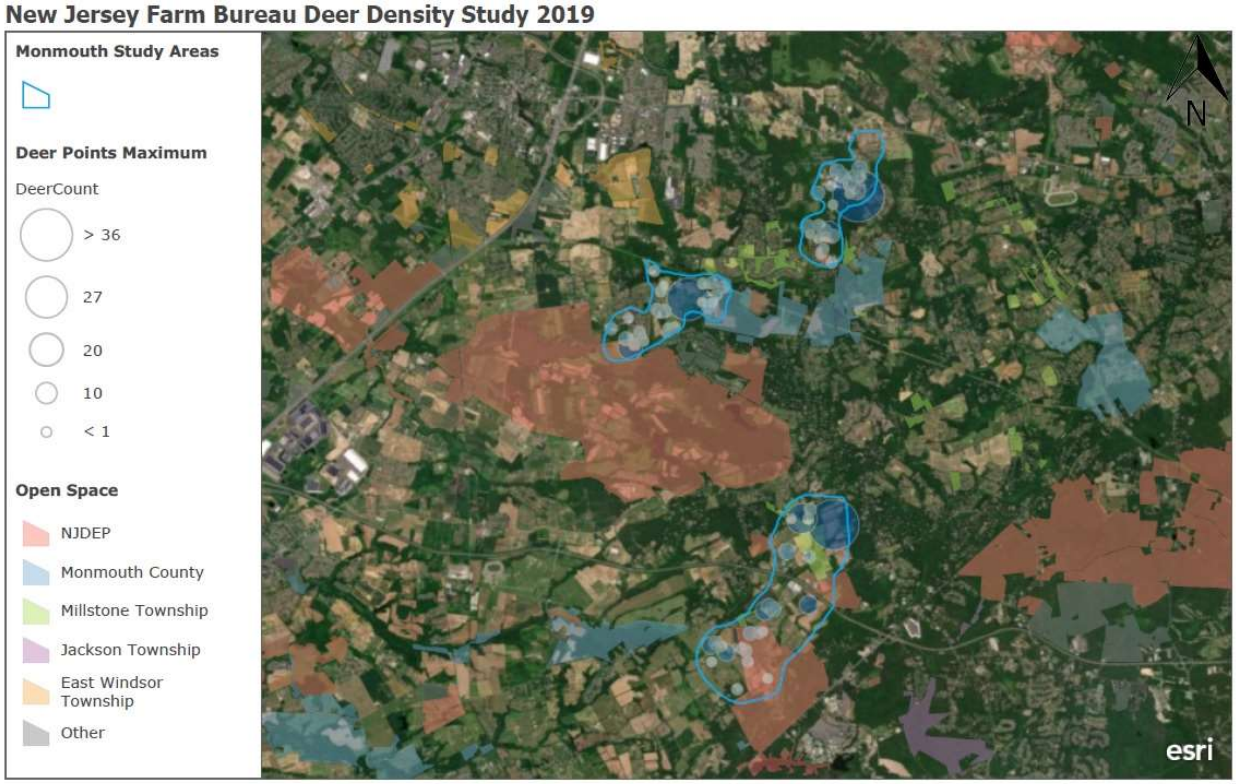
Date of Survey	Number of Missions	Total Number of Deer (min)	Deer per Square Mile (min)	Area Covered by sUAS (Acres)
April 17-18, 2019	9	344	65	3,390

Earthstar Geographics

Figure 7. **Maximum Deer Density Map, Monmouth County, NJ**



New Jersey Farm Bureau

StewardGreen™

Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 17-18, 2019	9	350	66	3,390

Earthstar Geographics

Figure 8. **Deer Density Maps Area 1 Northeast, Monmouth**

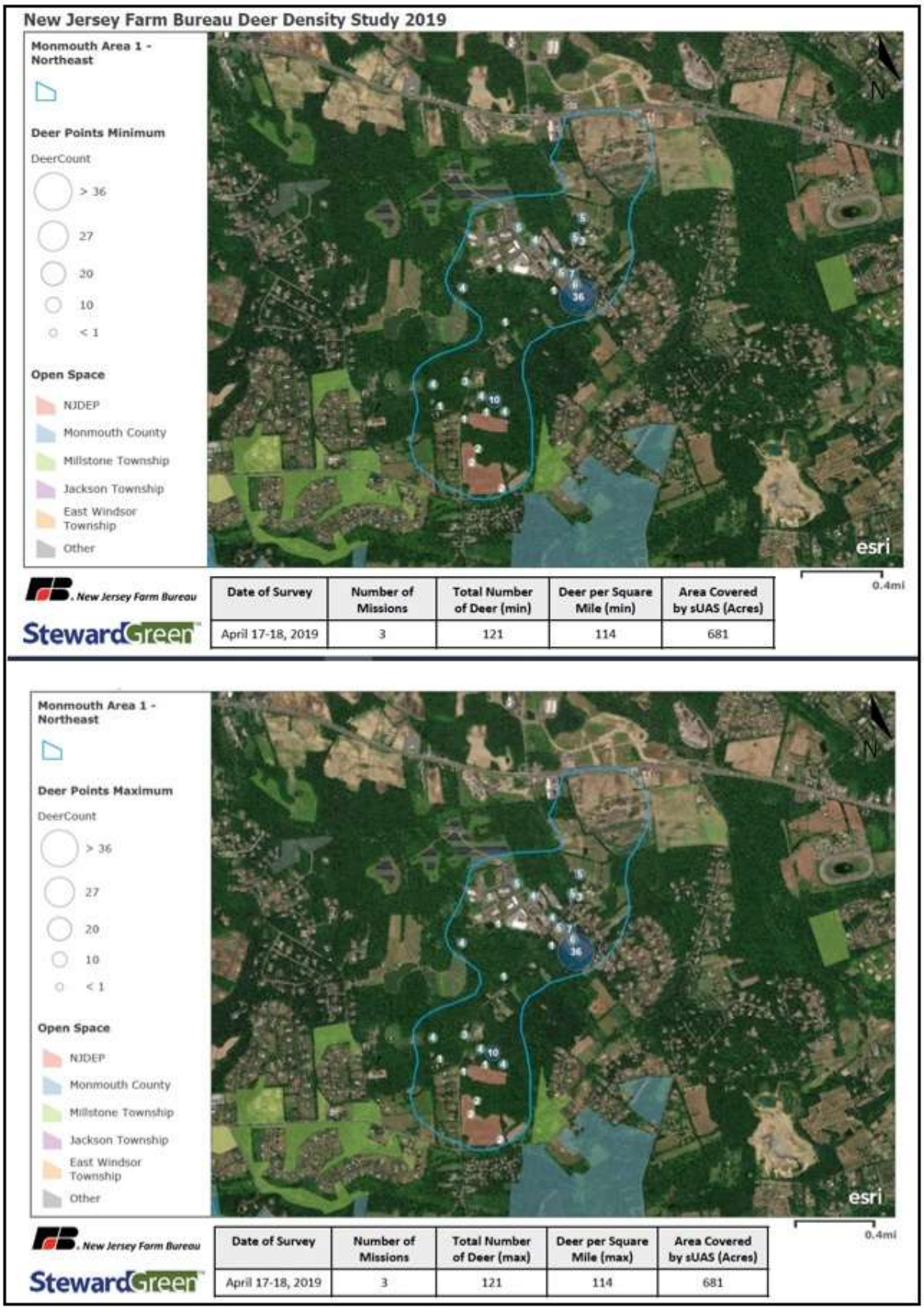
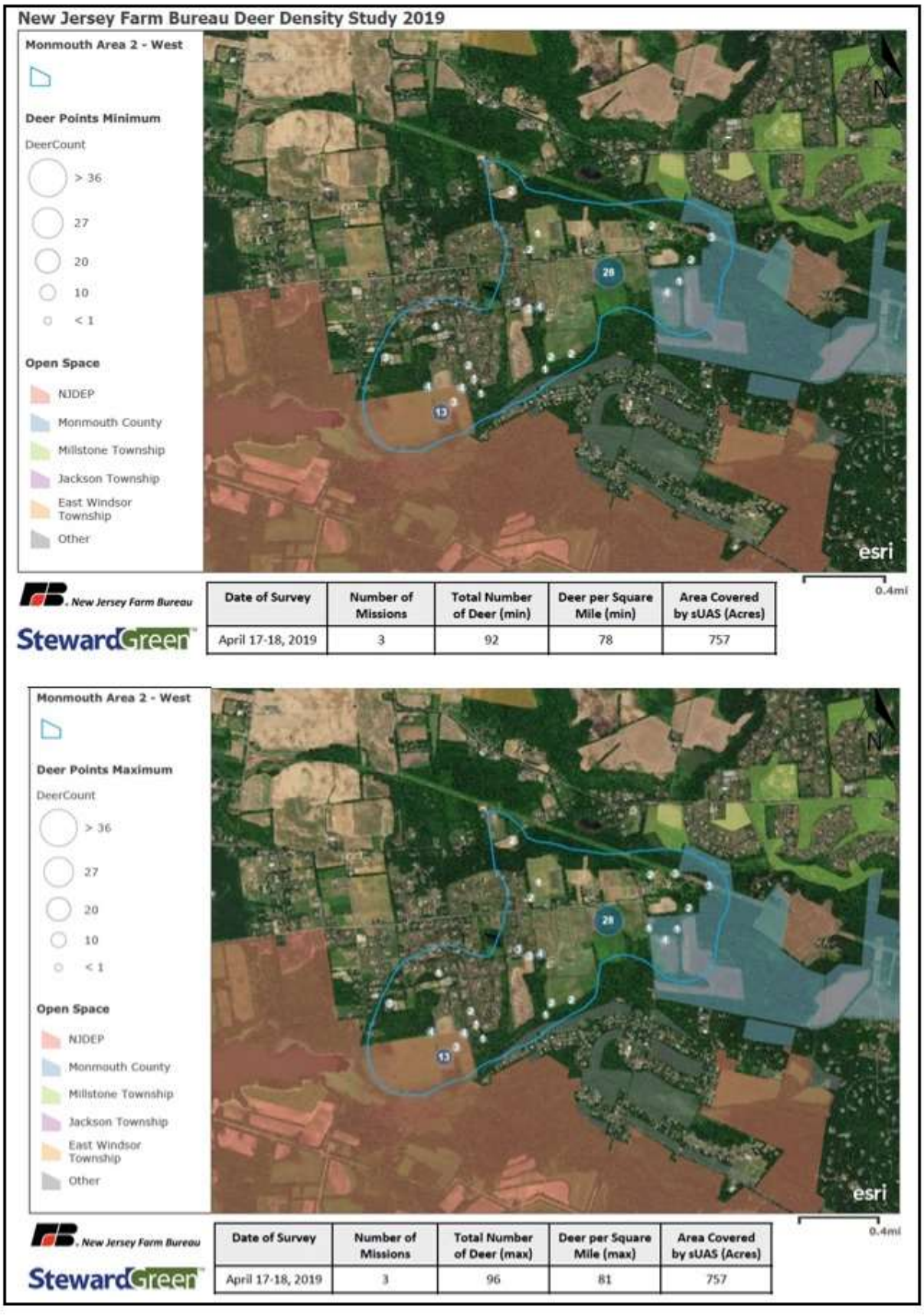


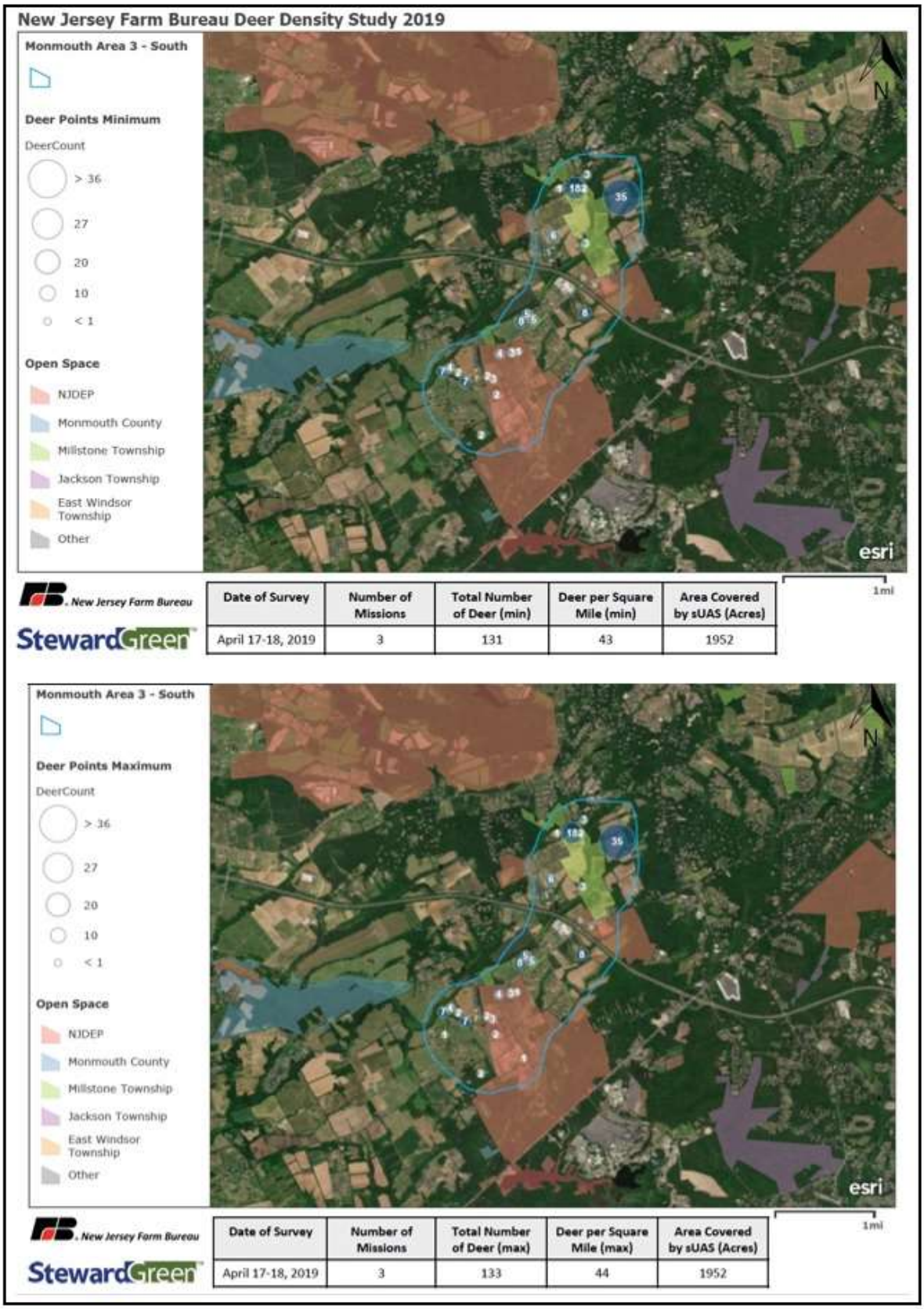
Figure 9. **Deer Density Maps Area 2 West, Monmouth**



Date of Survey	Number of Missions	Total Number of Deer (min)	Deer per Square Mile (min)	Area Covered by sUAS (Acres)
April 17-18, 2019	3	92	78	757

Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 17-18, 2019	3	96	81	757

Figure 10. **Maximum Deer Density Maps Area 3, South, Monmouth**



-End of Appendix D-

Appendix E

White-Tailed Deer (*Odocoileus virginiana*) Population Density Survey using sUAS Infrared; New Jersey Farm Bureau, Passaic County

Study Area. Areas sampled encompassed (3) study areas totaling approximately 940 acres or 1.5 square miles, consisting of a mix of upland woodland, agricultural fields, golf courses, residential, fragmented woodland parcels, wetlands and minor open water. These areas were chosen because of their varied agricultural uses and the deer damage reported at County Board of Agriculture meetings. Neighboring towns include Wayne, Pompton Lakes, Riverdale, Butler, Kinnelon and West Milford. Apshawa Preserve, Silas Condict County Park, Echo Lake, Norvin Green State Forest, Wanaque Reservoir, William Paterson University and High Mountain Reserve Park are all surrounding or close by. *See Figures 1 and 2*.

Figure 1. **Passaic County NJFB Deer Population Density Study State Orientation Map**

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Figure 2. **Passaic County NJFB Deer Population Density Study Area 1 Northwest, Area 2 East and Area 3 Southeast**.

Process. Site reconnaissance included FAA mandatory daytime inspections of the project area to evaluate ingress/egress, potential launch/landing points, site hazards, obstructions, flight patterns, etc. High voltage electric lines and towers, cell phone and radio towers, water towers, severe changes in elevation, large trees, etc. Launch/landing sites were also pre-determined. *See Figure 3.*

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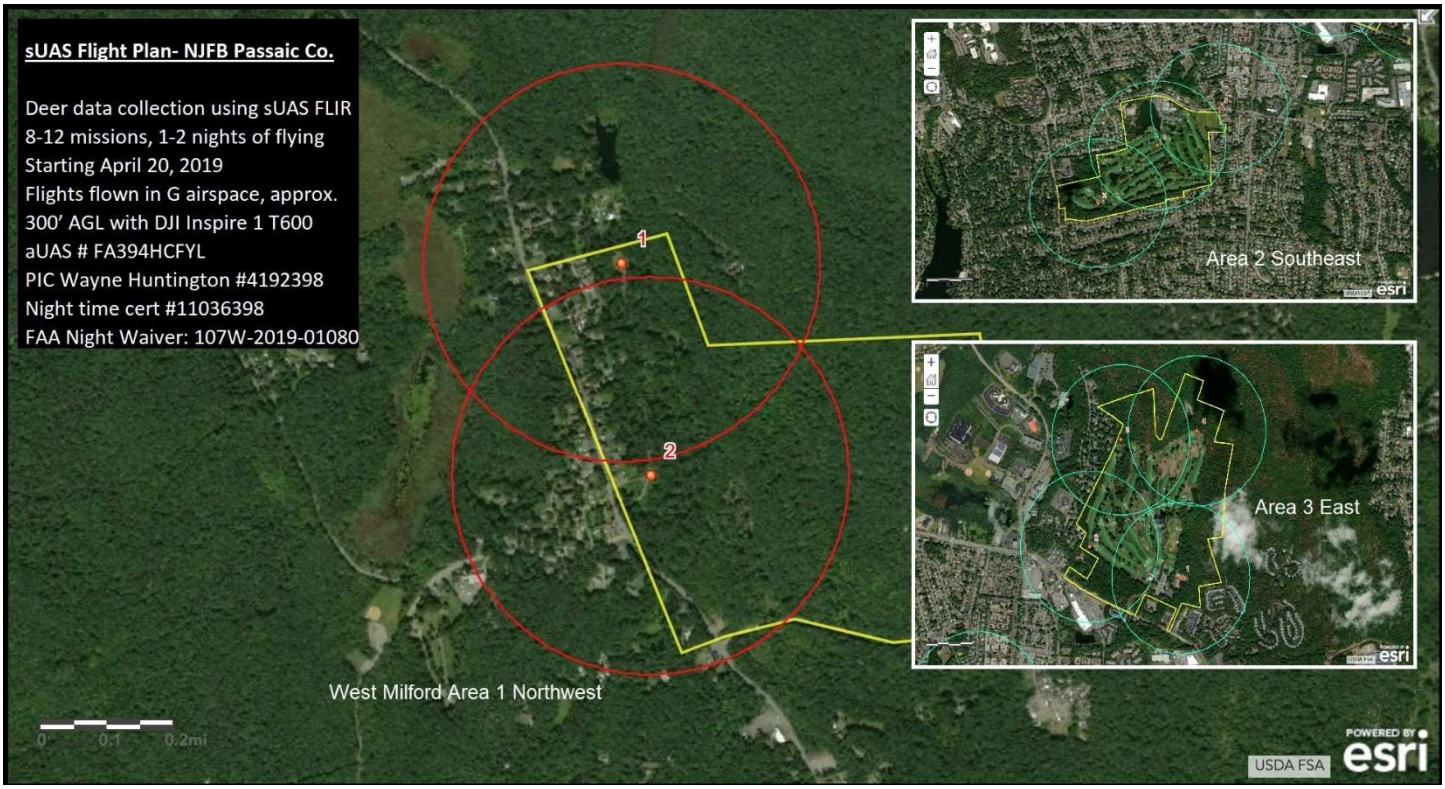
Figure 3. **sUAS Launch/land coverage Map and Flight Plan for Passaic County**.



The Passaic County study areas required 12 missions the nights of early mornings of April 28 & 29, covering areas systematically, with one Pilot in Command (PIC), Visual Observer (VO), observer familiar with the land and small Unmanned Aerial Vehicles (sUAVs). Temperature on April 29th at 1am was 44° F with fair skies and waning crescent moon, providing excellent conditions to collect thermal data. Deciduous trees had not yet leafed out and evergreen tree coverage was minimal. Other heat signatures observed included boulders, field springs, pockets of water, streams, streetlights, active chimneys, drain inlets, electric transformers, cars in driveways, pets and other mammals.

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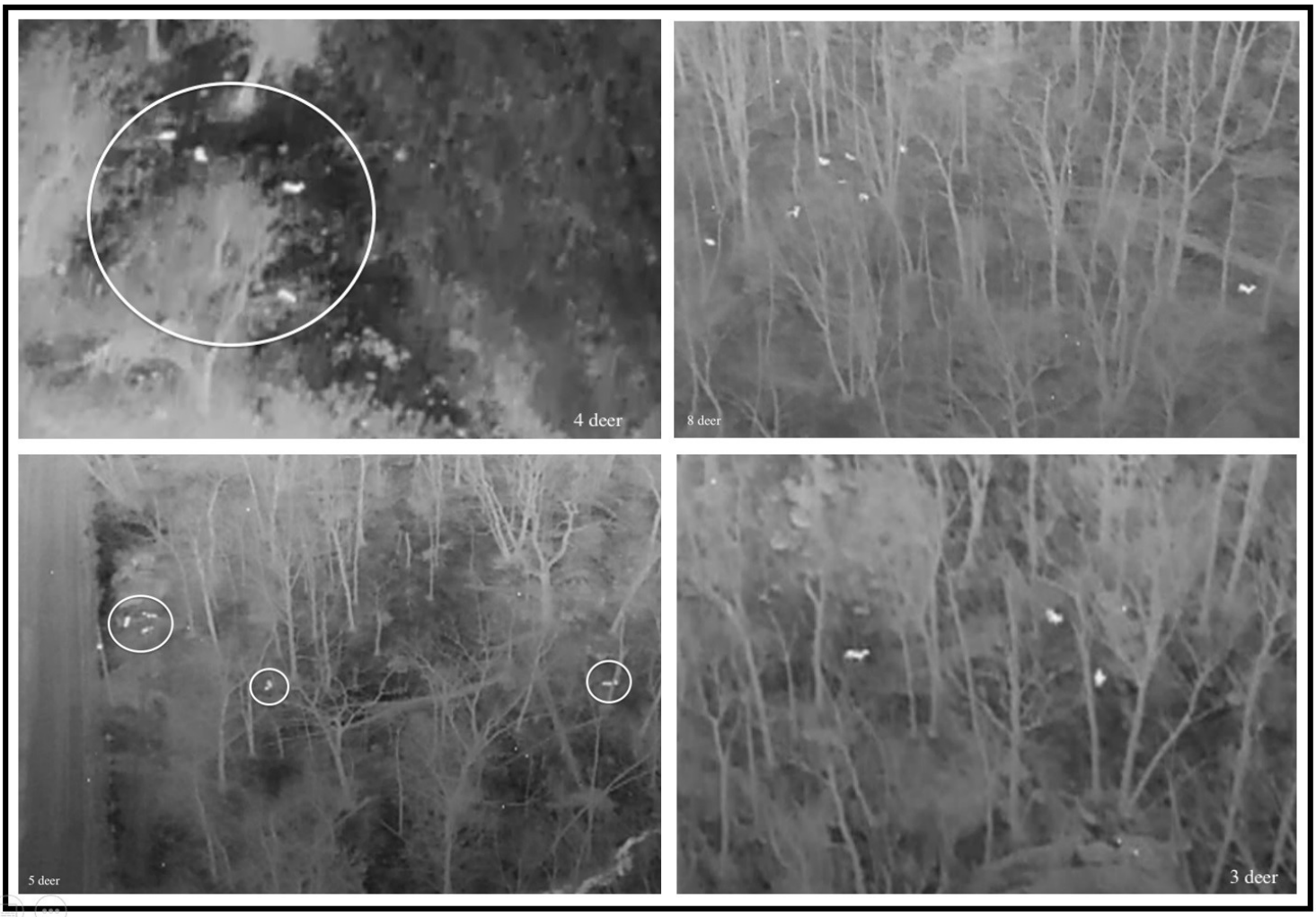
Figure 4. Thermal imagery examples, NJFB Passaic County



Images were collected using a Vertical Take-Off and Landing (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. We completed a quality saturation data collection of all project areas flown, approximately 940 acres or 1.5 square miles. The Passaic County sampling was represented by 3 areas; Area 1 Northwest, Area 2 East and Area 3 Southeast. These areas were then broken into smaller units due to coverage capability. Deer heat signatures were visible and clear, contrasting with colder surrounds and demonstrating scale. *See Figure 4.*

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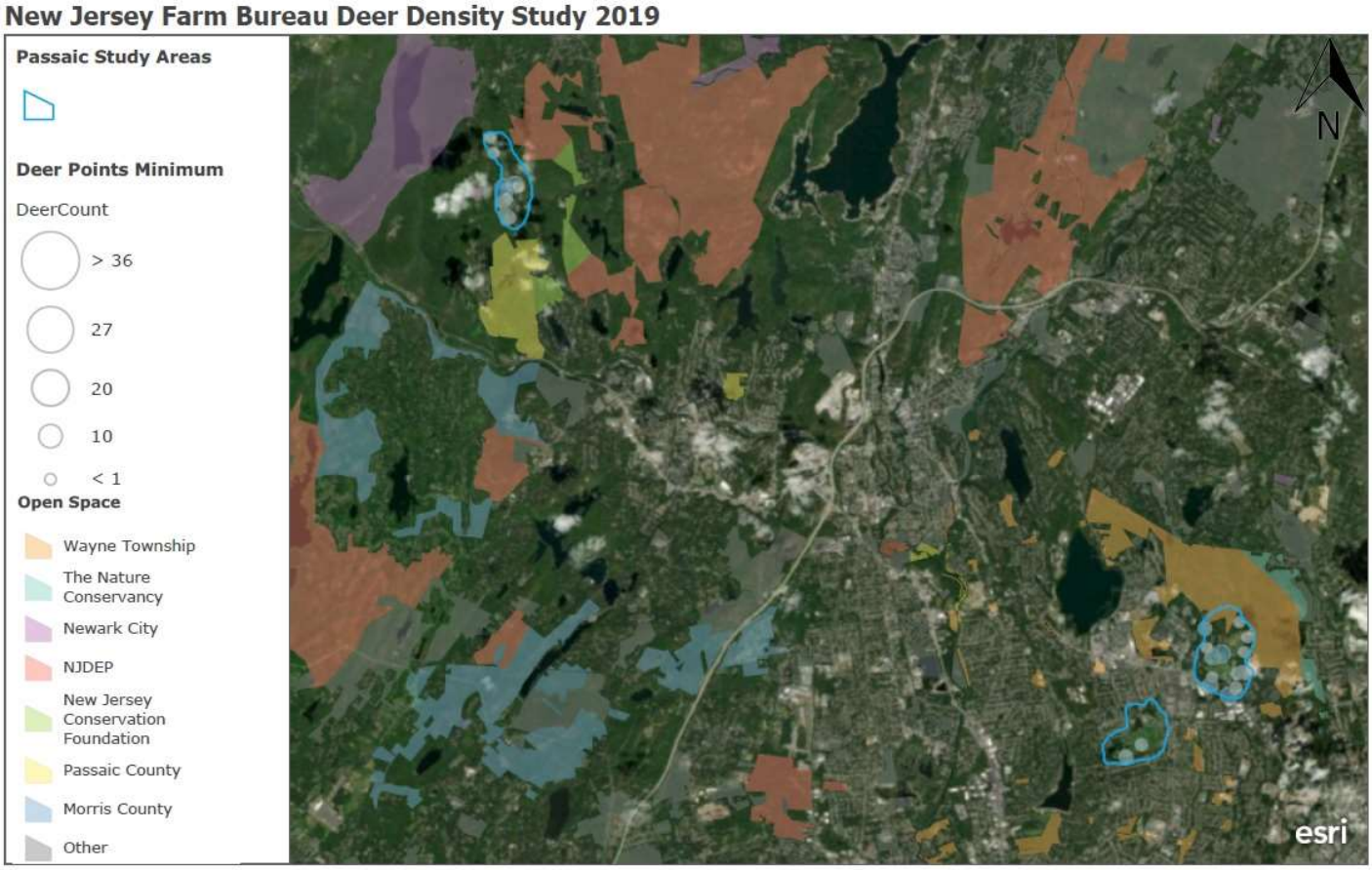
Figure 5. **Minimum Deer Density Map, Passaic County, NJ**



New Jersey Farm Bureau

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Date of Survey	Number of Missions	Total Number of Deer (min)	Deer per Square Mile (min)	Area Covered by sUAS (Acres)
April 23, 28-29, 2019	12	65	44	940

Earthstar Geographics

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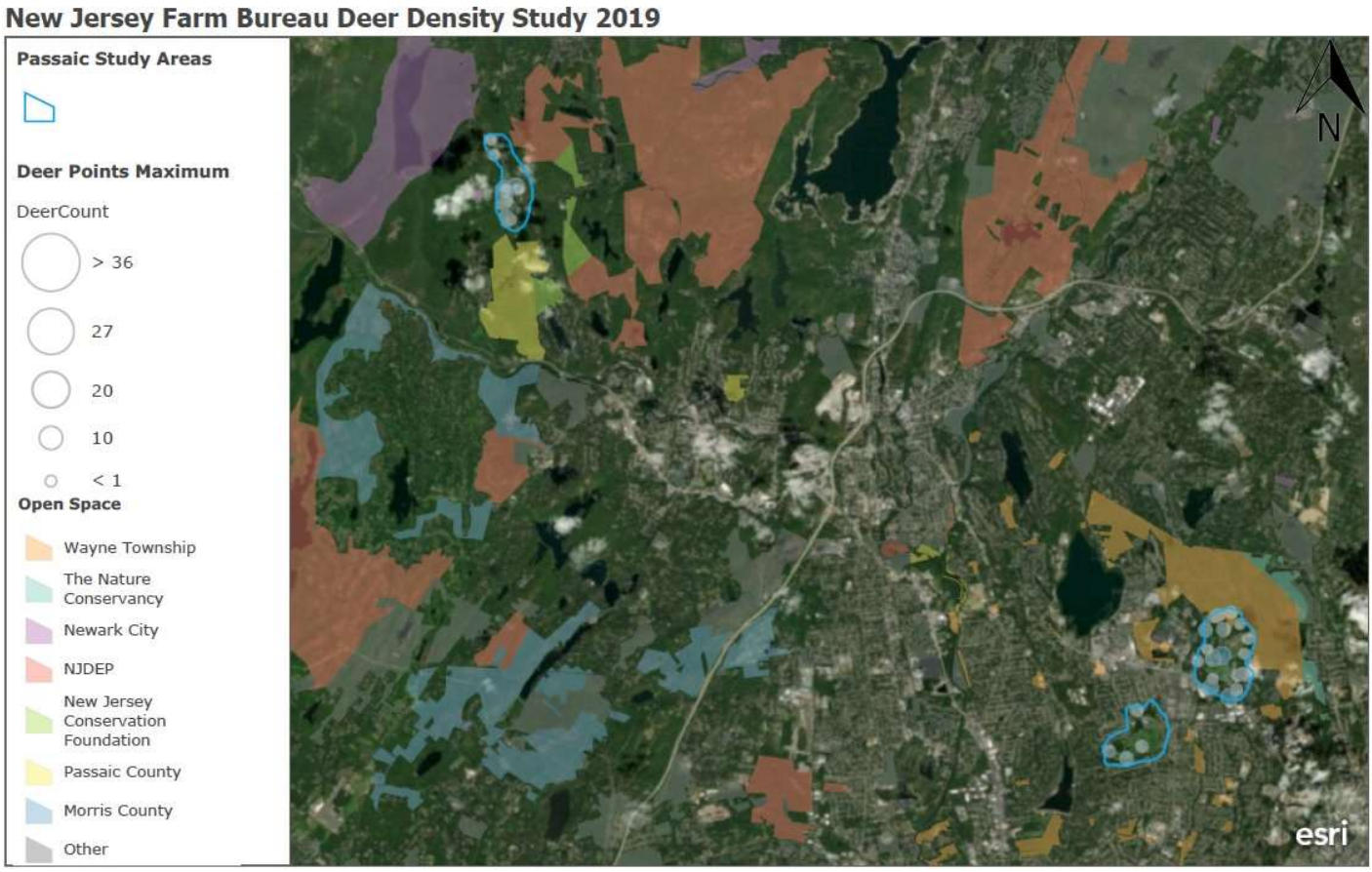
Figure 6. **Maximum Deer Density Map, Passaic County, NJ**



Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 23, 28-29, 2019	12	81	55	940

Earthstar Geographics

Results. At a minimum, there were 65 deer counted in the sampling areas, which equates to 44 deer per square mile for areas sampled in the data collection. At maximum, there were 81 deer counted in the sampling areas, which equates to 55 deer per square mile for areas sampled in the data collection. *See Figures 5, 6, 7, 8, 9 and Table 1.*

Table 1. **Deer Density- Maximum vs. Minimum, Passaic County, NJ**

Passaic County:					
	Acres	Deer Max	Max SM	Deer mir	Min SM
Area 1 Northwest	255	27	68	24	60
Area 2 East	278	9	21	5	12
Area 3 Southeast	407	45	71	36	57
Totals:	940	81	55	65	44

Figure 7. **Deer Density Maps Area 1 Northwest**

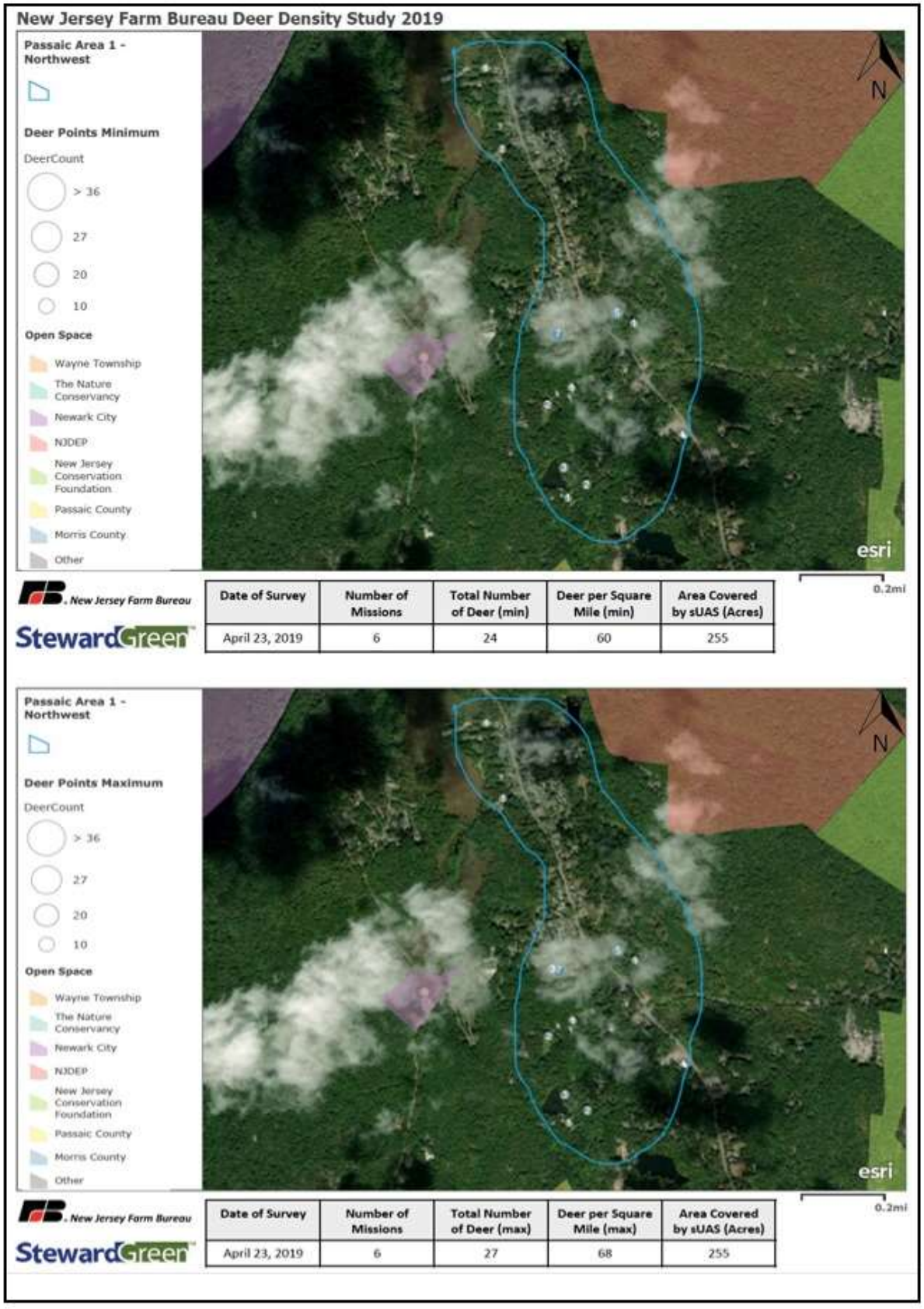


Figure 8. **Deer Density Maps Area 2 East**

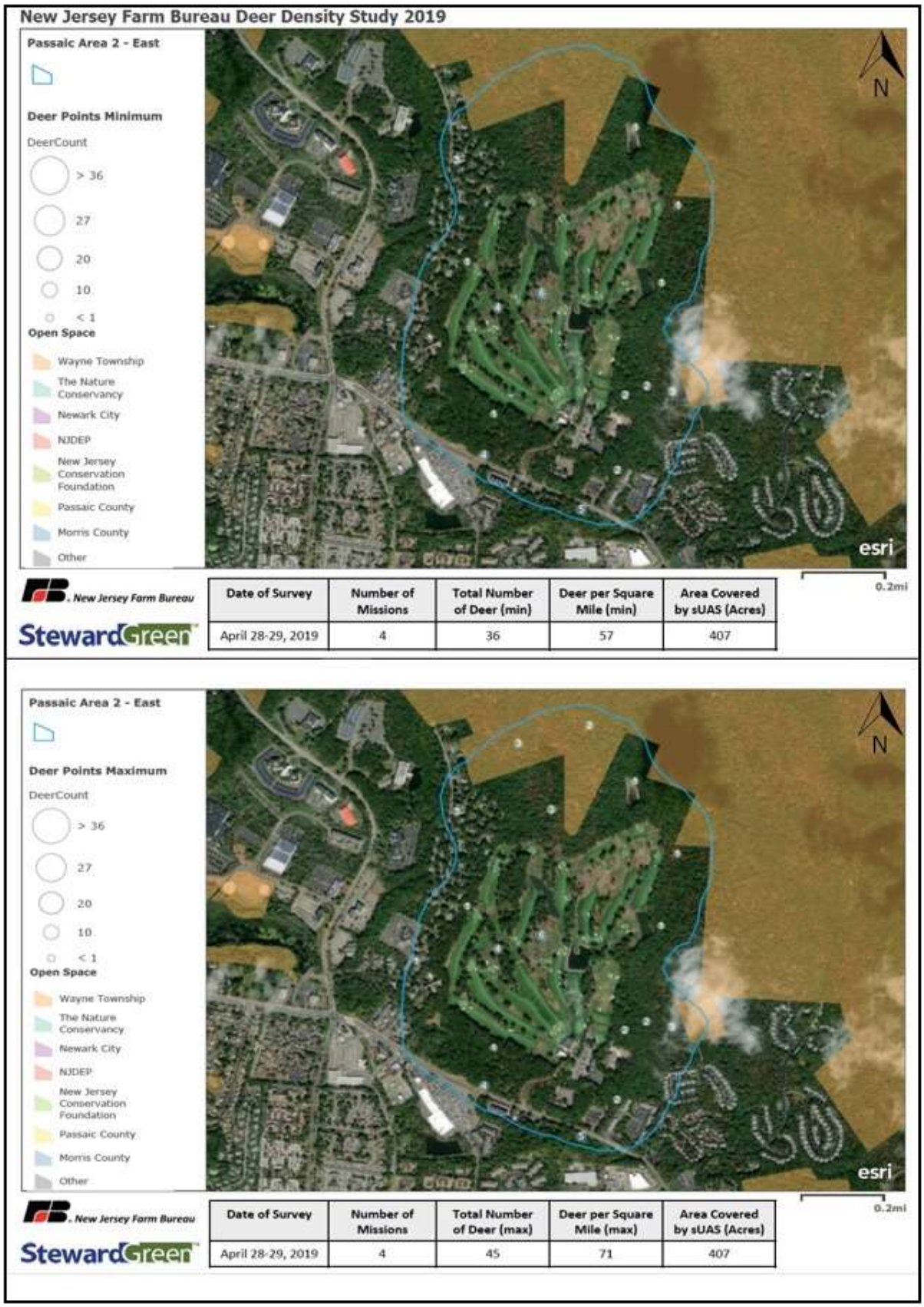


Figure 9. **Deer Density Maps Area 3, Southeast**

-End of Appendix E-

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Appendix F

Preliminary Report: White-Tailed Deer (*Odocoileus virginiana*) Population Density Survey using sUAS Infrared; New Jersey Farm Bureau, Somerset County

Study Area. Areas sampled encompassed (2) study areas totaling approximately 2,834 acres or 4.43 square miles, consisting of a mix of upland woodland, agricultural fields, residential, fragmented woodland parcels, wetlands and minor open water. The Mattawang Golf Course, located in Montgomery Township, lies within "Area 1 West". Part of Six Mile Run and the Negri-Nepote Native Grassland Preserve are located within the Franklin Township "Area 1 East" study area. The Millstone River and Colonial Park lie to the east, Duke Farms is to the northwest. Sourland Mountain Preserve is nearby. *See Figures 1, 2 and 3*.

Figure 1. **Somerset County NJFB Deer Population Density Study Area location map**.

Figure 2. **Somerset County NJFB Deer Population Density Study Area 1 West, Hillsborough Township**.

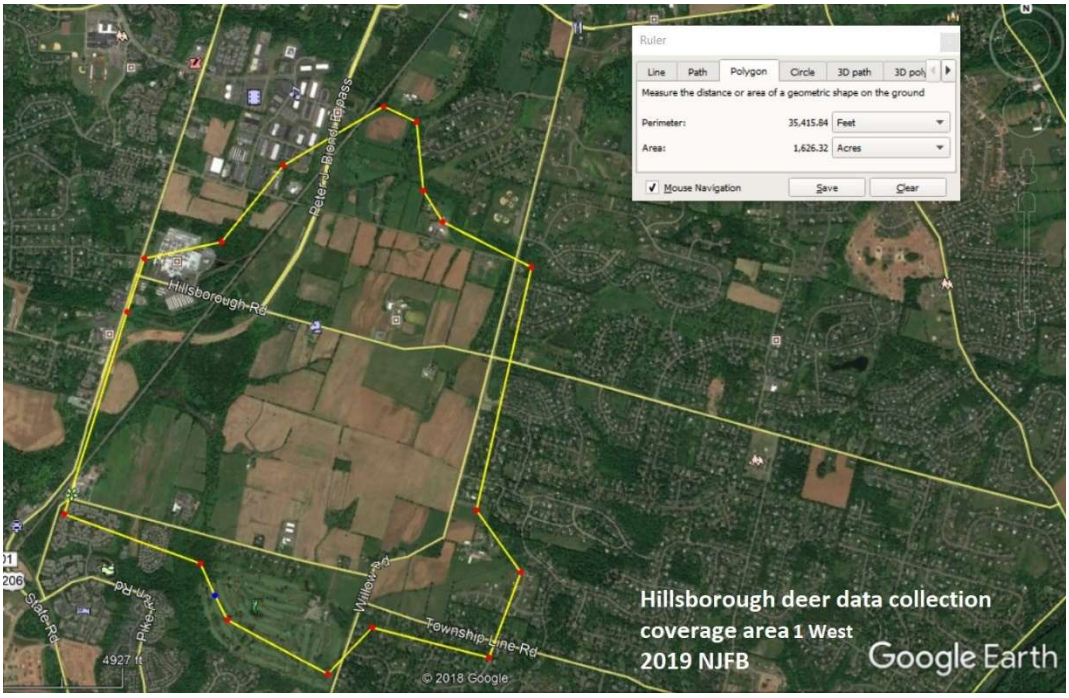
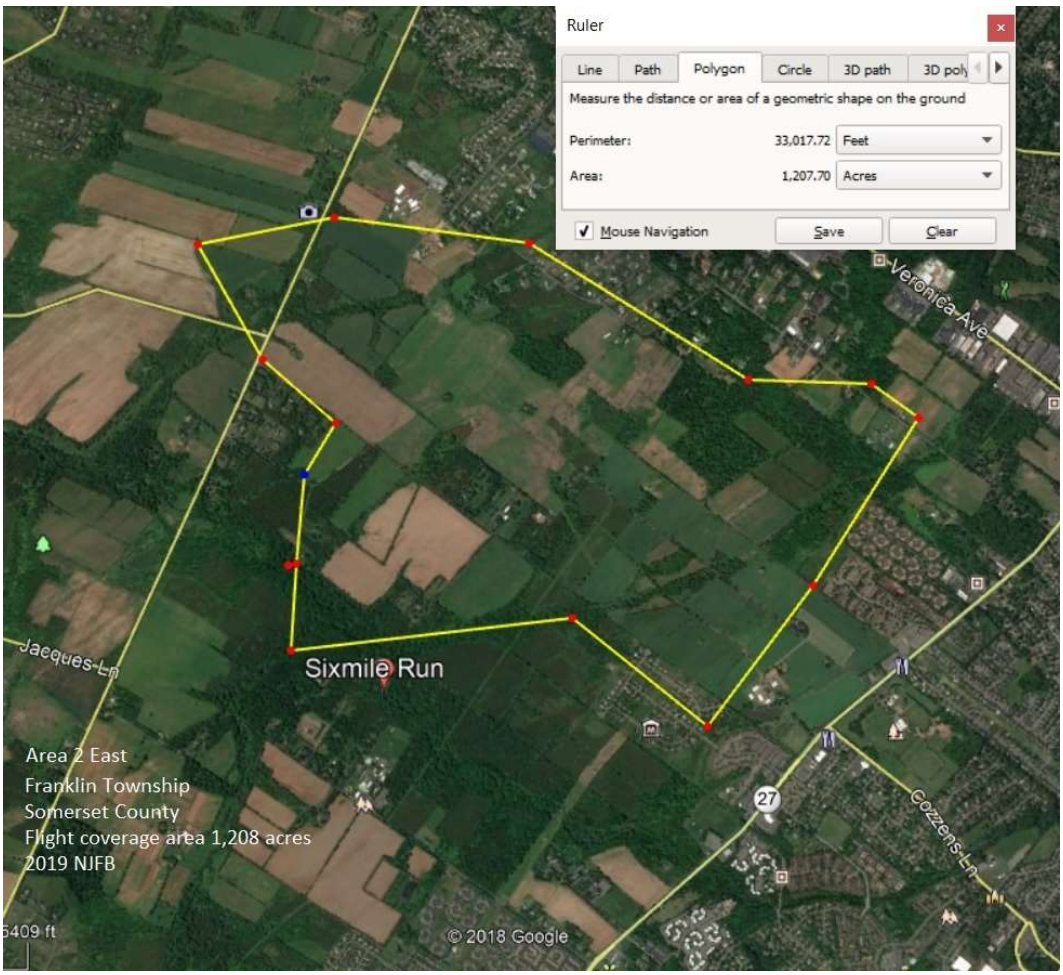


Figure 3. **Somerset County NJFB Deer Population Density Study Area 2 East, Franklin Township**.



Process. Site reconnaissance included FAA mandatory daytime inspections of the project area to evaluate ingress/egress, potential launch/landing points, site hazards, obstructions, flight patterns, etc. High voltage electric lines and towers, cell phone and radio towers, water towers, severe changes in elevation, large trees, etc. Launch/landing sites were also pre-determined. *See Figures 4 and 5.*

Figure 4. **sUAS Launch/land coverage Map and Flight Plan for Area 1 West, Hillsborough Township**.

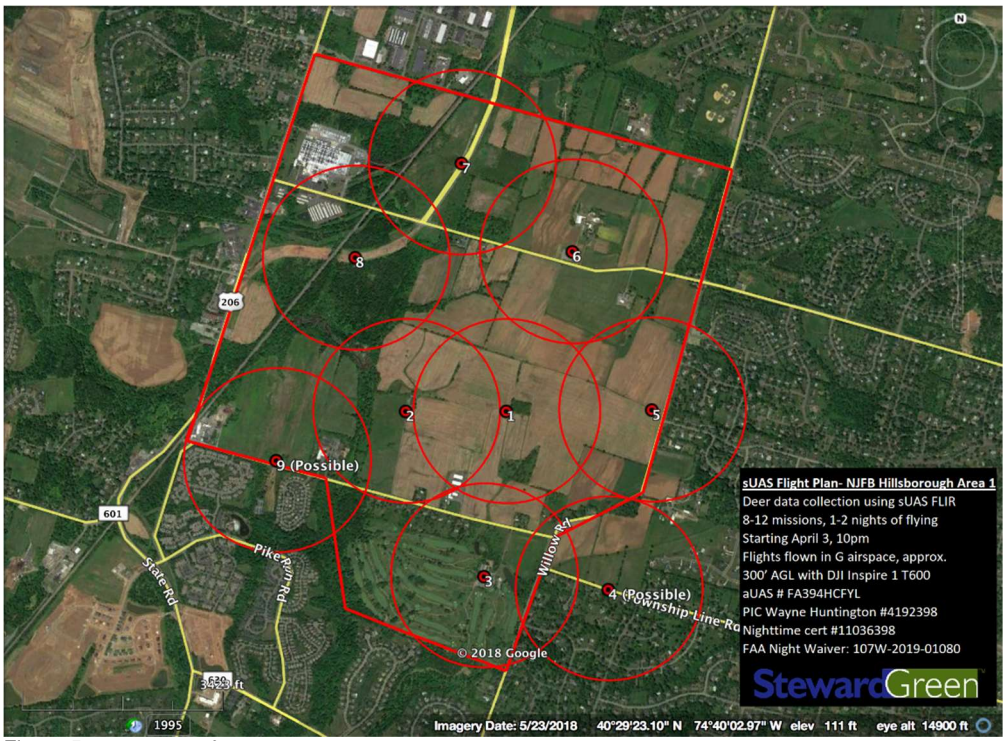
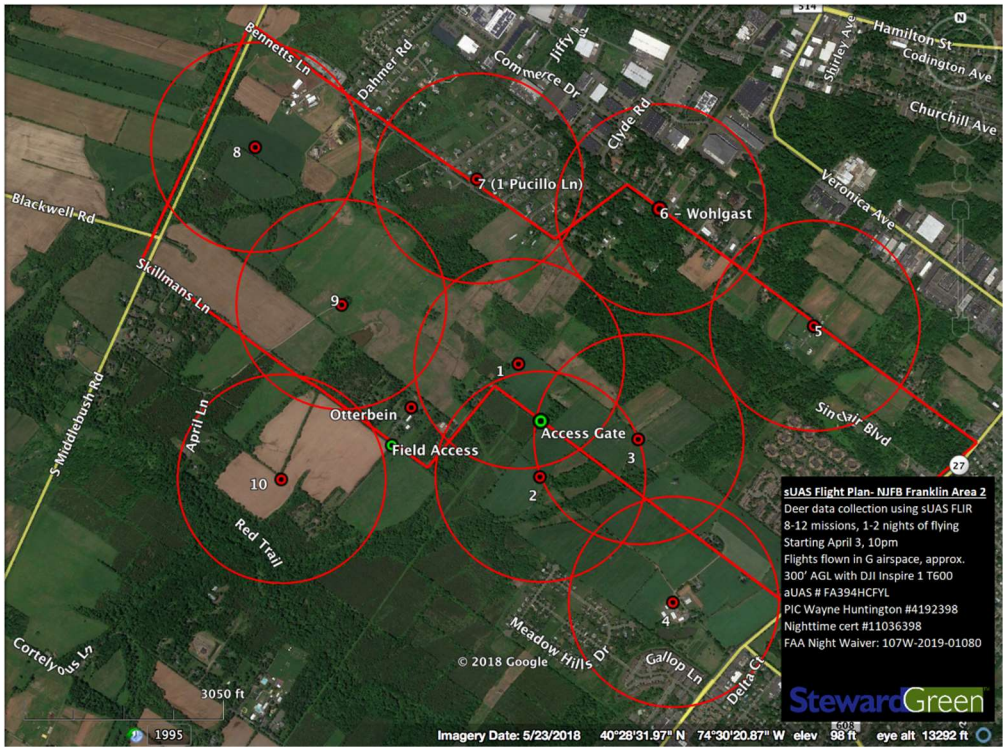


Figure 5. **sUAS Launch/land coverage Map and Flight Plan for Area 2 East, Franklin Township**.



The Somerset County study areas required 4 missions the nights of early mornings of April 3-5, covering areas systematically, with one Pilot in Command (PIC), Visual Observer (VO), observer familiar with the land and small Unmanned Aerial Vehicles (sUAVs). Temperature on April 3 at 1am was 39-41° F with clear to fair skies and waning crescent to new moon, providing excellent conditions to collect thermal data. Deciduous trees had not yet leafed out and evergreen tree coverage was minimal. Other heat signatures observed included boulders, field springs, pockets of water, streams, streetlights, active chimneys, drain inlets, electric transformers, cars in driveways, pets and other mammals.

Figure 6. Thermal imagery example, NJFB Somerset County; Area 2 East, Franklin Township

Images were collected using a Vertical Take-Off and Landing (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. A quality saturation data collection of all project areas flown was completed, of approximately 2,834 acres or 4.43 square miles. The Somerset County sampling was represented by two areas; Area 1 West in Hillsborough Township and Area 2 East in Franklin Township. These areas were then broken into smaller units due to coverage capability. Deer heat signatures were visible and clear, contrasting with colder surroundings and demonstrating scale. *See Figures 6, 7 and 8.*

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Figure 7. Thermal imagery example, NJFB Somerset County, Areas 1 & 2

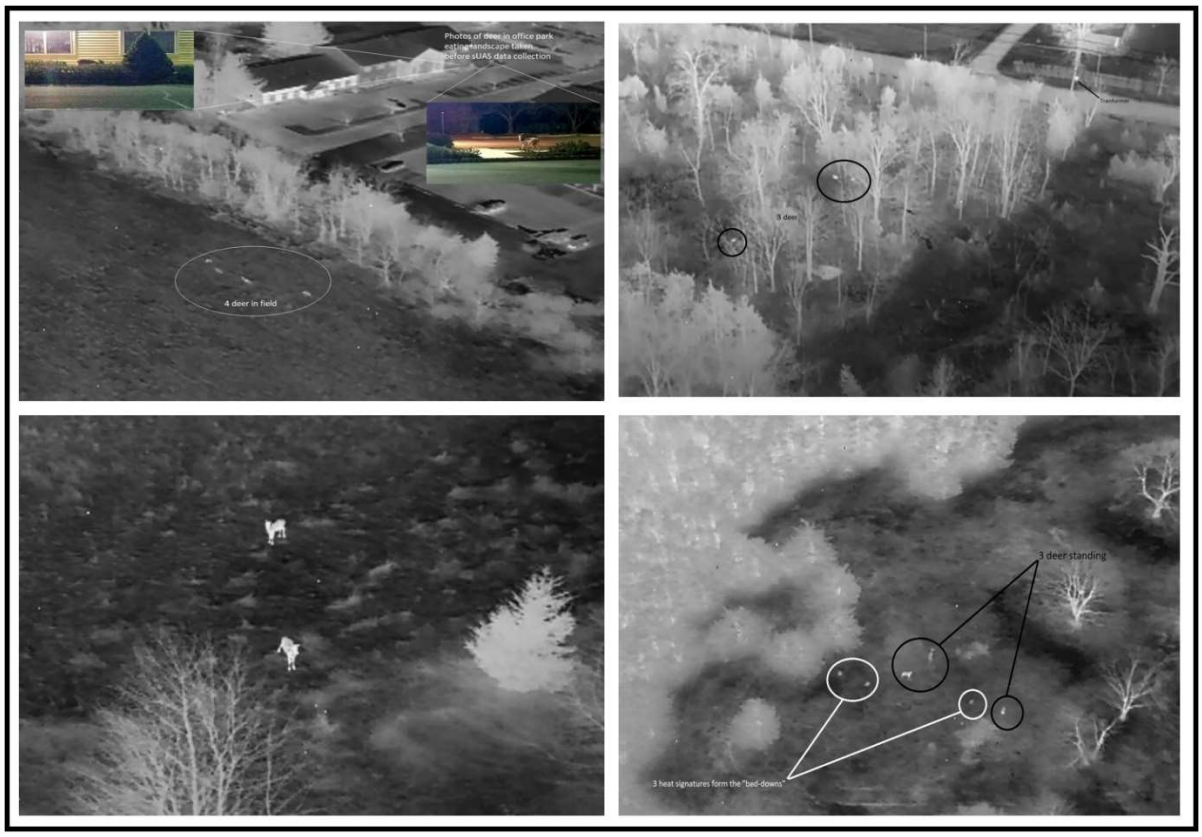


Figure 8. **Thermal imagery example, NJFB Somerset County, Areas 1 & 2**

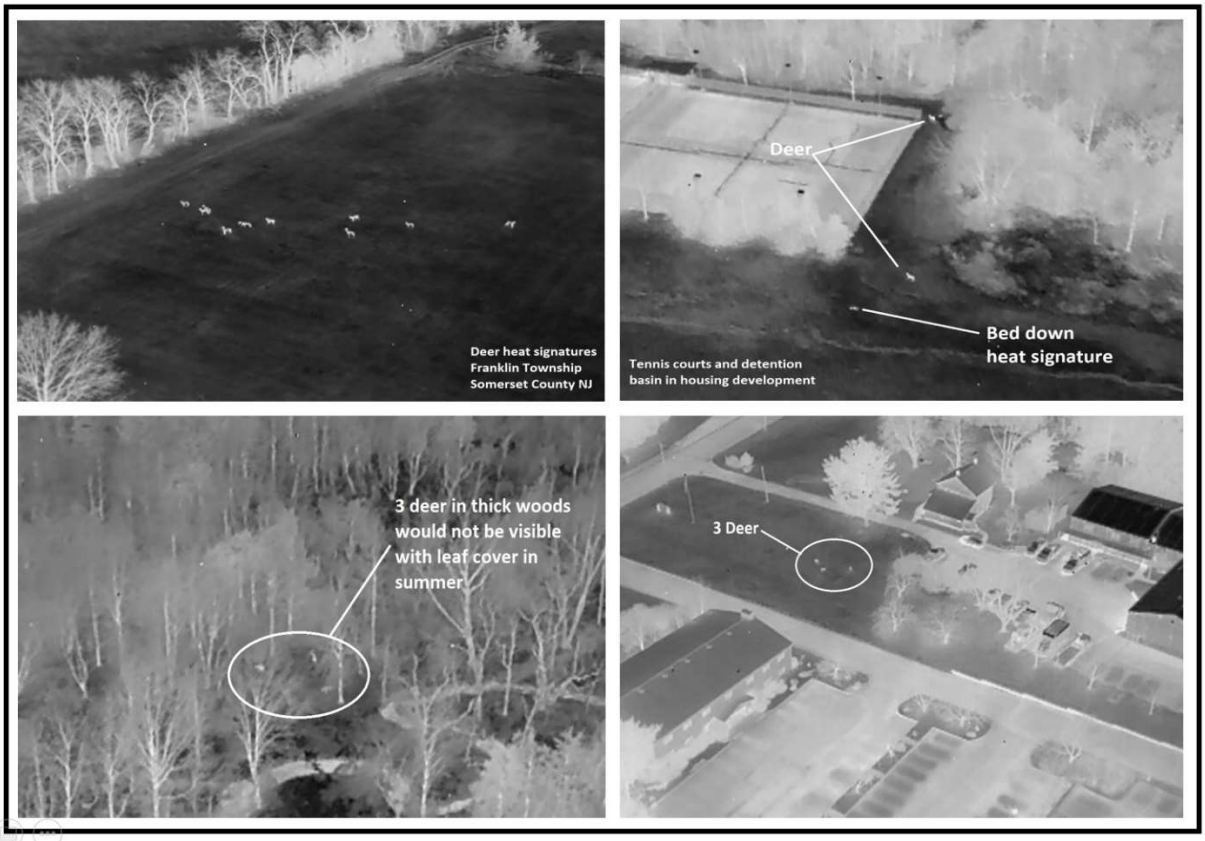
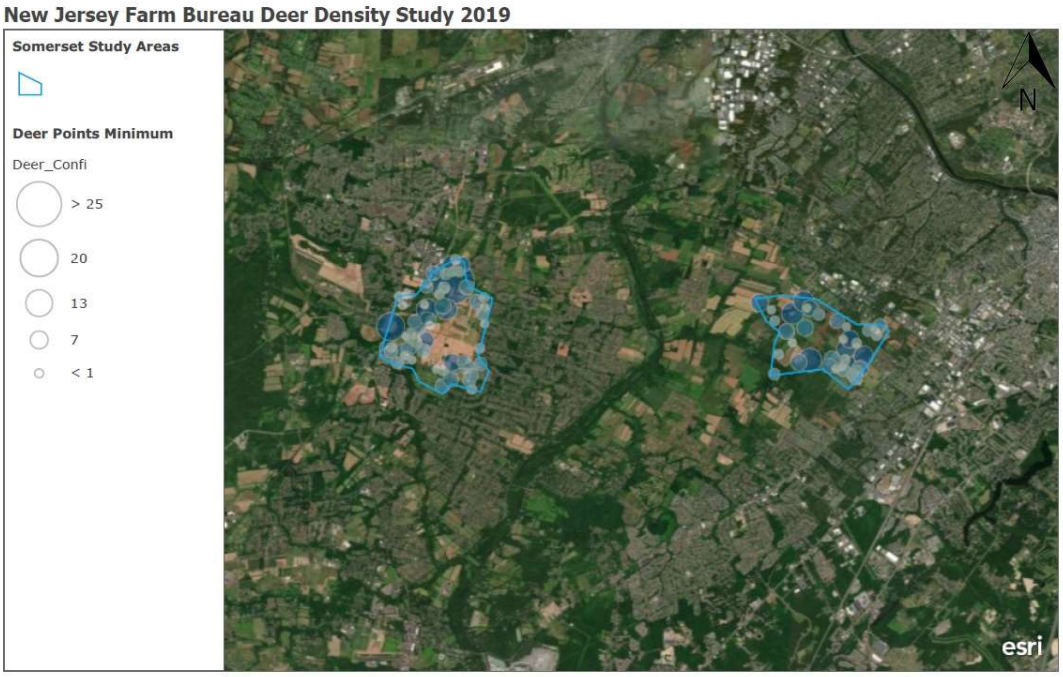


Figure 9. **Minimum Deer Density Map, Somerset County, NJ**



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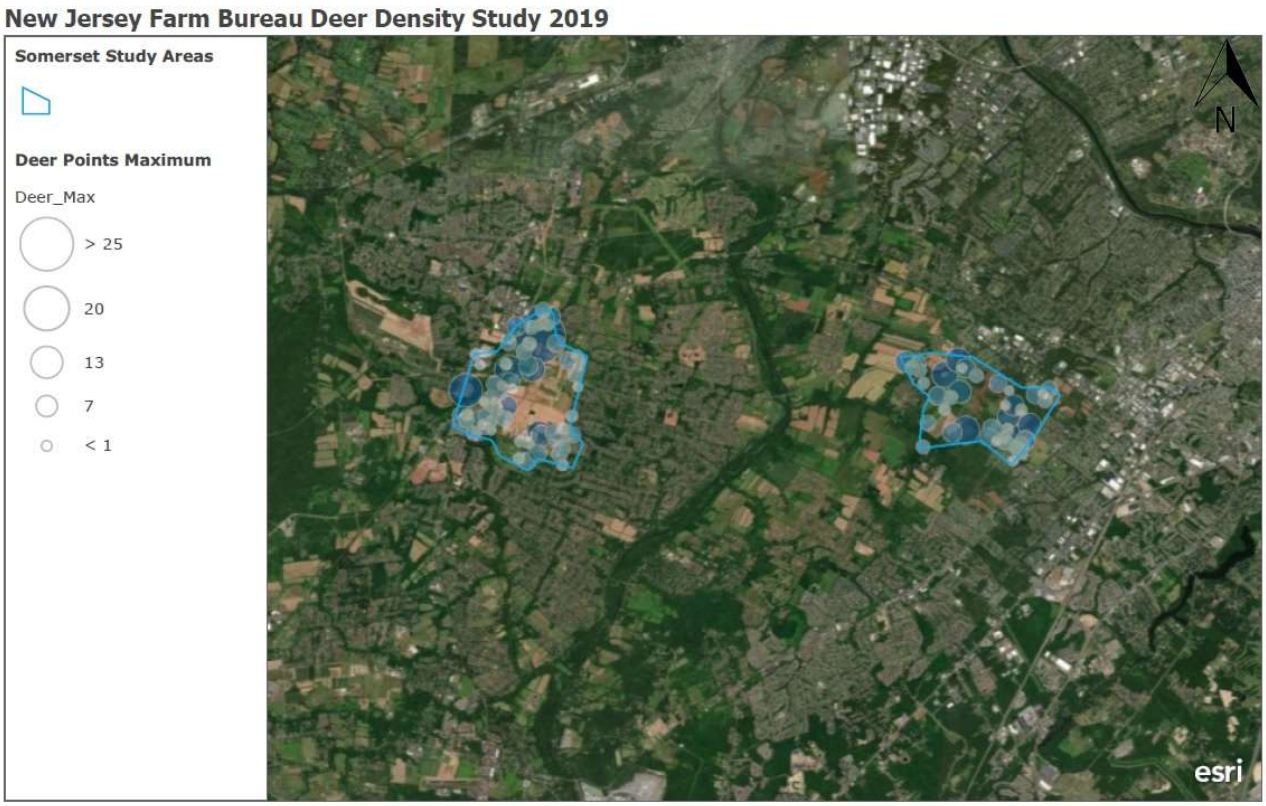
Date of Survey	Number of Missions	Total Number of Deer (min)	Deer per Square Mile (min)	Area Covered by sUAS (Acres)
April 3-5, 2019	21	402	91	2,834

Earthstar Geographics

Figure 10. **Maximum Deer Density Map, Somerset County, NJ**



New Jersey Farm Bureau
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Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 3-5, 2019	21	446	101	2,834

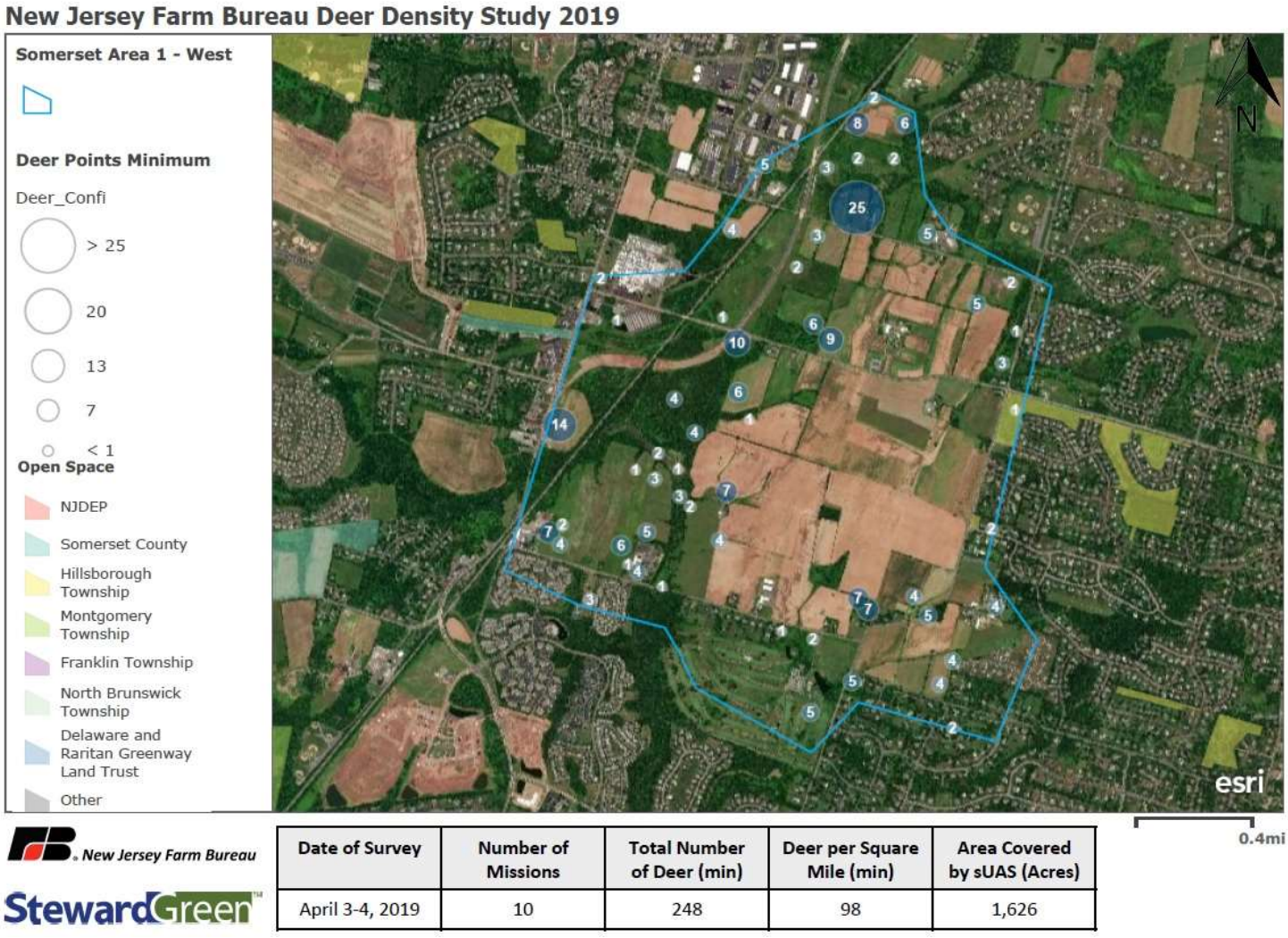
Earthstar Geographics

Results. At a minimum, there were 402 deer counted in the sampling areas, which equates to 91 deer per square mile for areas sampled in the data collection. At maximum, there were 446 deer counted in the sampling areas, which equates to 101 deer per square mile for areas sampled in the data collection. *See Figures 9, 10, 11, 12, 13, 14 and Table 1.*

Table 1. **Deer Density- Maximum vs. Minimum, Somerset County, NJ**

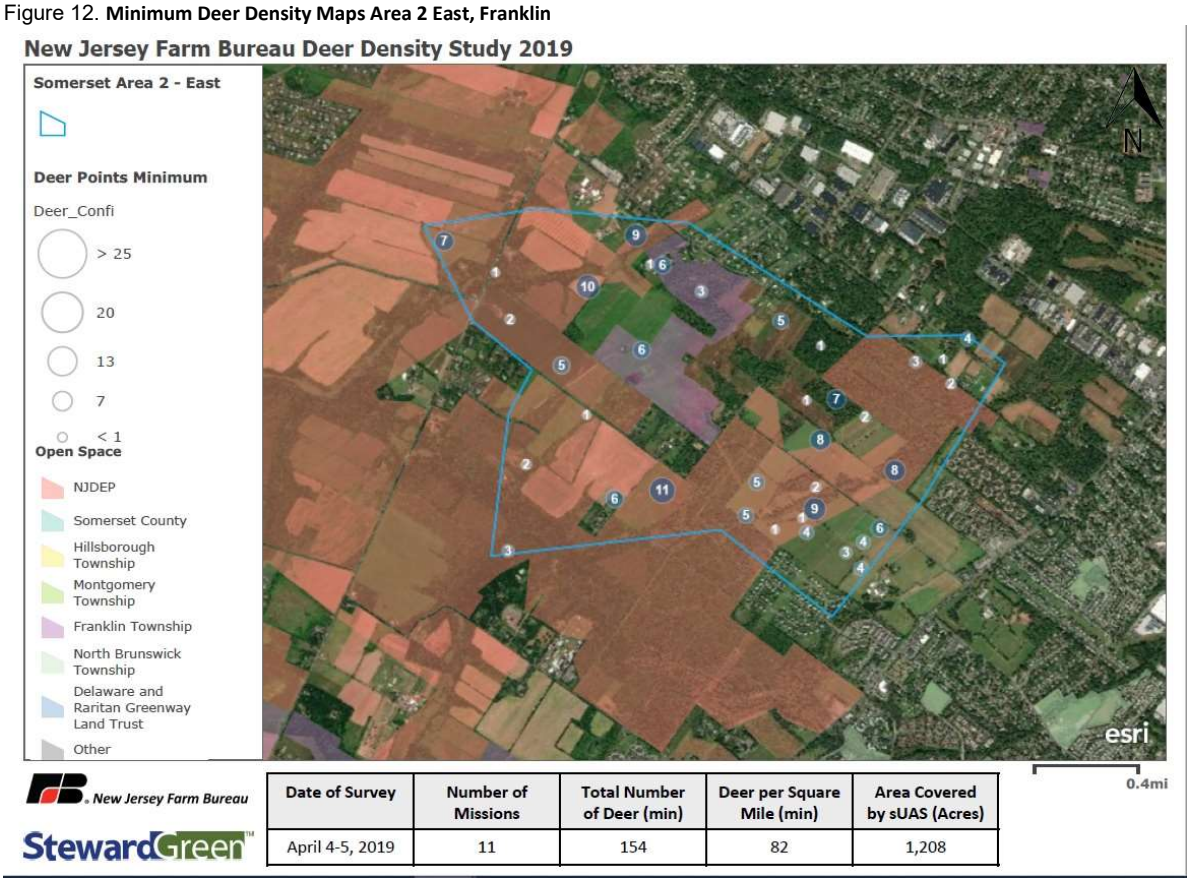
Somerset County:					
	Acres	Deer Max	Max SM	Deer min	Min SM
Area 1 West	1626	268	105	248	98
Area 2 East	1208	178	94	154	82
Totals:	2834	446	101	402	91

Figure 11. **Minimum Deer Density Map Area 1 West, Hillsborough**



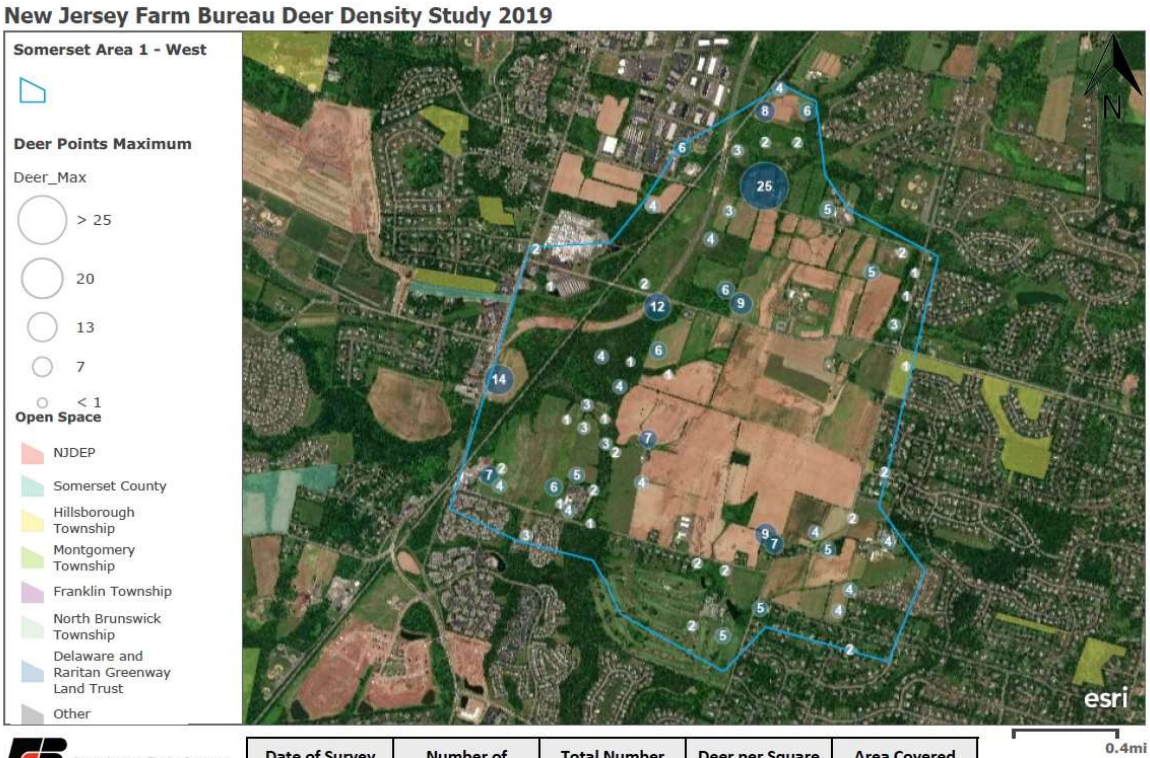
Date of Survey	Number of Missions	Total Number of Deer (min)	Deer per Square Mile (min)	Area Covered by sUAS (Acres)
April 3-4, 2019	10	248	98	1,626

Figure 12. **Minimum Deer Density Maps Area 2 East, Franklin**



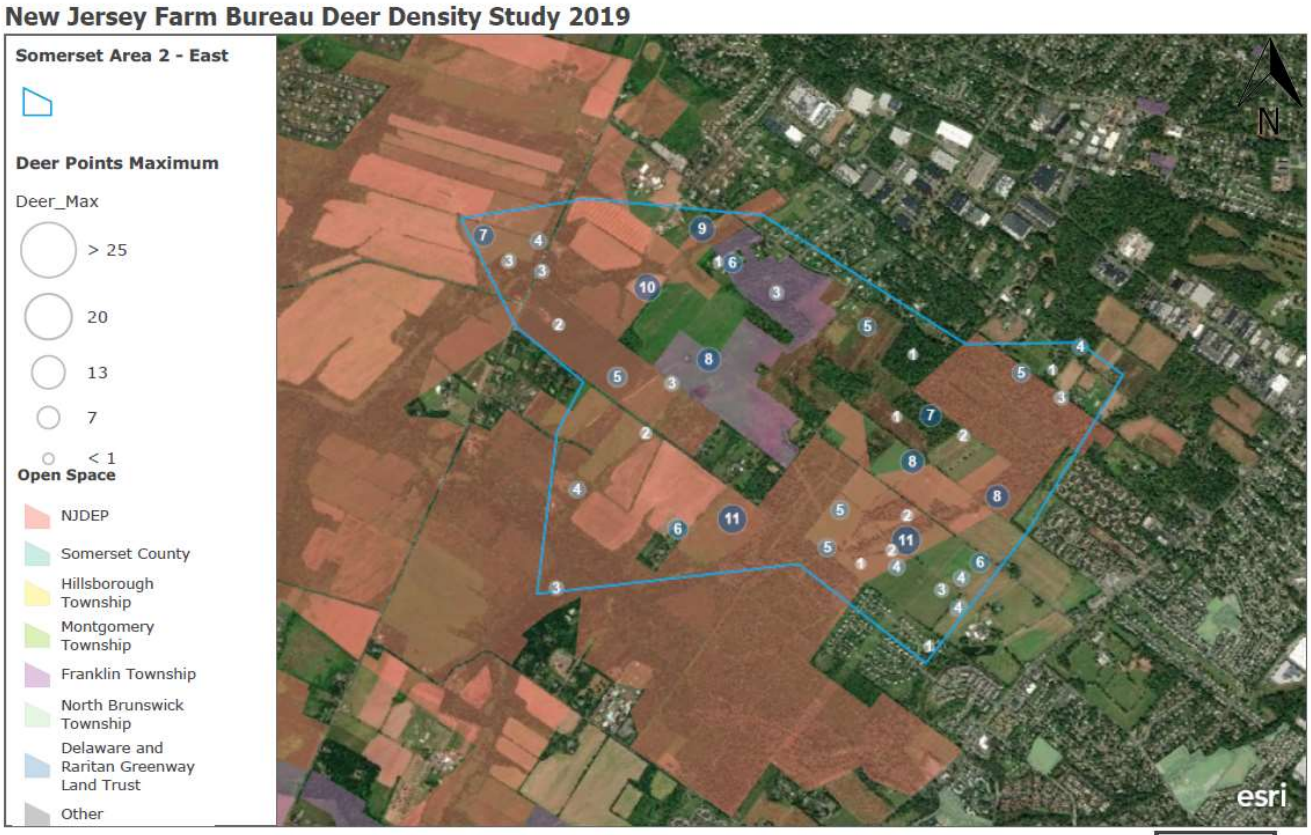
Date of Survey	Number of Missions	Total Number of Deer (min)	Deer per Square Mile (min)	Area Covered by sUAS (Acres)
April 4-5, 2019	11	154	82	1,208

Figure 13. **Maximum Deer Density Maps Area 1 West, Hillsborough**



Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 3-4, 2019	10	268	105	1,626

Figure 14. **Maximum Deer Density Maps Area 2 East, Franklin**



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Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 4-5, 2019	11	178	94	1,208

-End of Appendix F-

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Appendix G

Chapter Report: White-Tailed Deer (*Odocoileus virginiana*) Population Density Survey using sUAS Infrared; Warren County, New Jersey Farm Bureau

Study Area. Warren County areas sampled encompassed (4) study areas totaling approximately 1,830 acres or 3 square miles, consisting mostly of large agricultural fields (soybeans field corn and hay), some residential, fragmented woodlands, open space parcels and minor open water. The Delaware River lies to the west, Merrill Creek Reservoir, the town of Harmony to the southwest and the town of Washington to the southeast. Buckhorn Creek Wildlife Management Area, Buckhorn Creek, Roaring Rock Park and Montana Mountain are all in the vicinity. The study area is surrounded by much of the same type of agriculture and larger tracts of open space and forested lands. *See Figures 1, 2 and 3*.

Figure 1. **Warren County NJFB Deer Population Density Study Area location map**.

Figure 2. **Warren County NJFB Deer Population Density Study Area with surrounding Open Space**.

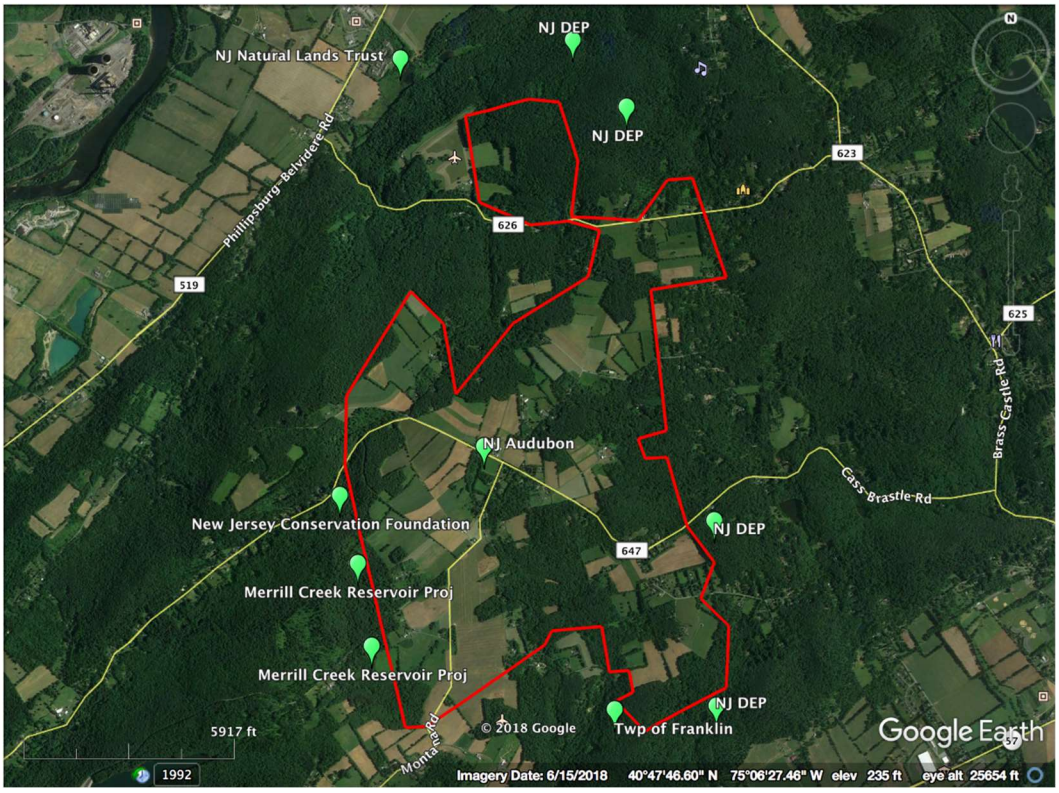
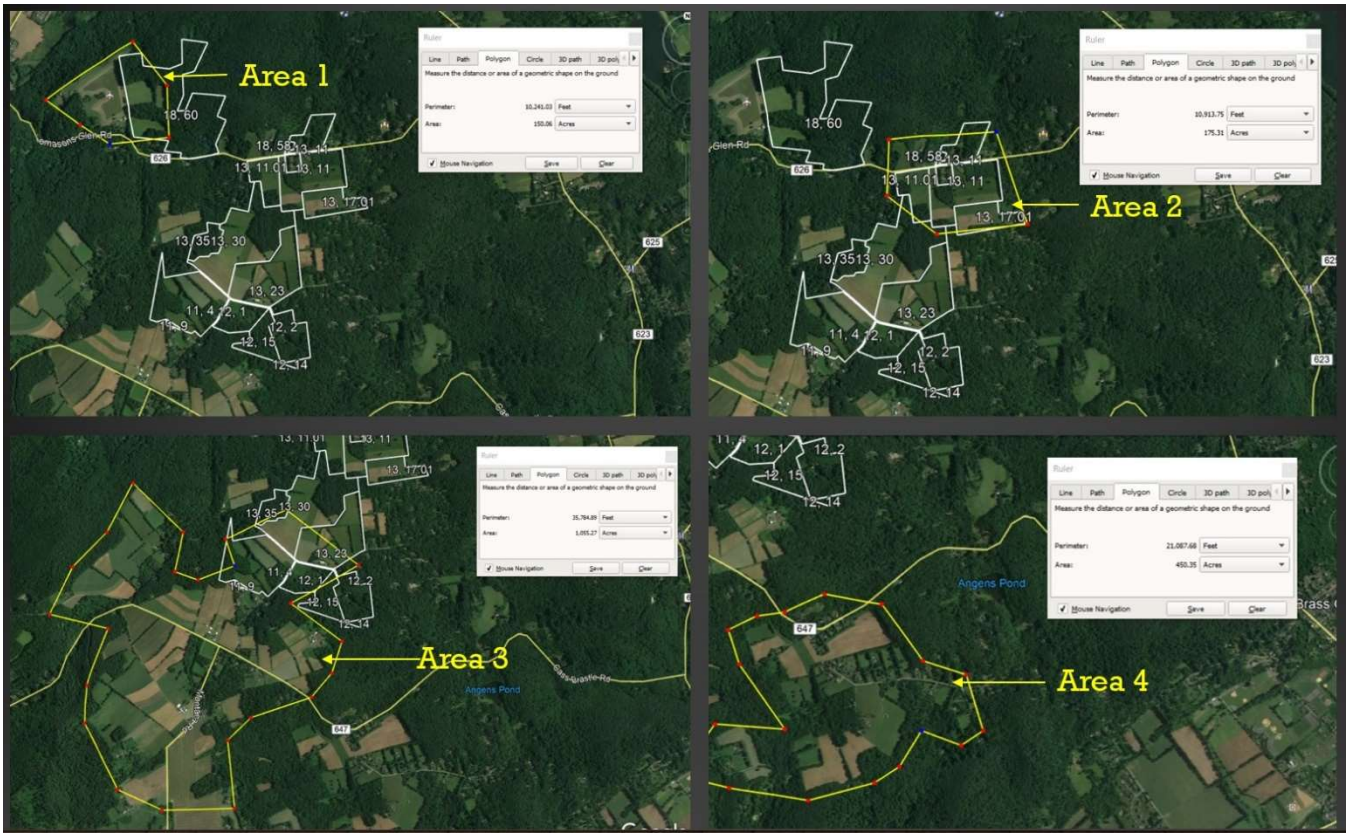
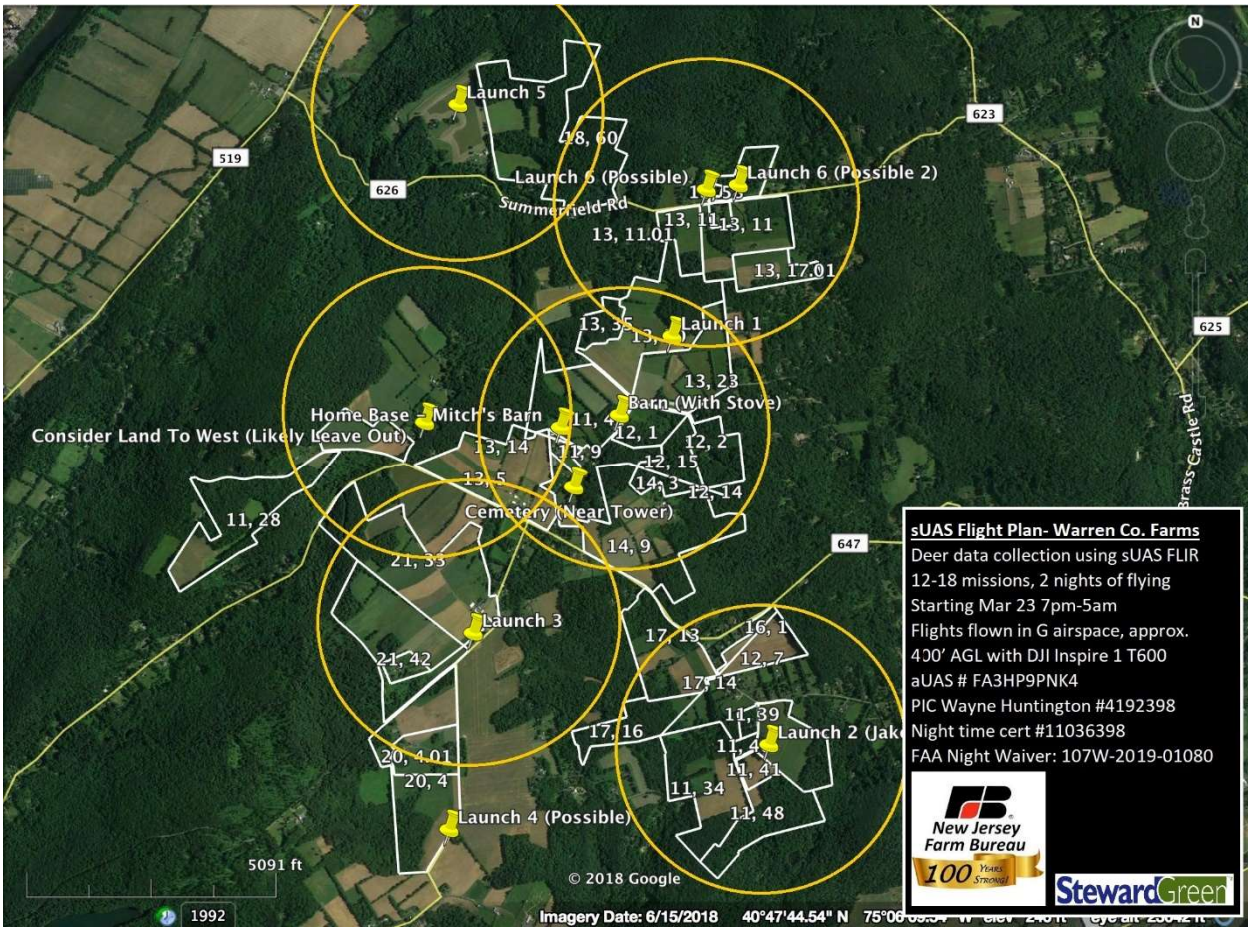


Figure 3. **Warren County NJFB Area Maps**.



Process. Site reconnaissance included 2 days of FAA mandatory daytime inspections of the project area to access ingress/egress, potential launch/landing points, site hazards, obstructions, flight patterns, etc. High voltage electric lines and towers, cell phone and radio towers, water towers, severe changes in elevation, large trees, etc., were noted during these investigations. Launch/landing sites were also pre-determined. *See Figure 4.*

Figure 4. **Warren County NJFB sUAS Launch/land coverage Map**.



The Warren County study areas required 11 missions the night of April 1 and early morning of April 2, covering areas systematically, at least once with one crew, pilot in command (PIC), visual observer (VO), observer familiar with the land and sUAV. Temperature on April 2nd at 1am was 26° F with fair skies and waning crescent moon, providing excellent conditions to collect thermal data. Deciduous trees had not yet leafed out and evergreen tree coverage was minimal to moderate. Other heat signatures observed included boulders, filed springs, pockets of water, streams, streetlights, active chimneys, drain inlets, electric transformers, cars in driveways and other mammals.

Images were collected using a VTOL small Unmanned Aerial System (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. Enough quality data was collected to conclude saturation data collection of all project areas flown, approximately 1,830 acres. The entire area was broken into 4 smaller units due to coverage capability. *See Figures 5 and 6*.

Figure 5. **Warren County NJFB Heat signature example**.

Figure 6. **Warren County NJFB Heat signature examples**.

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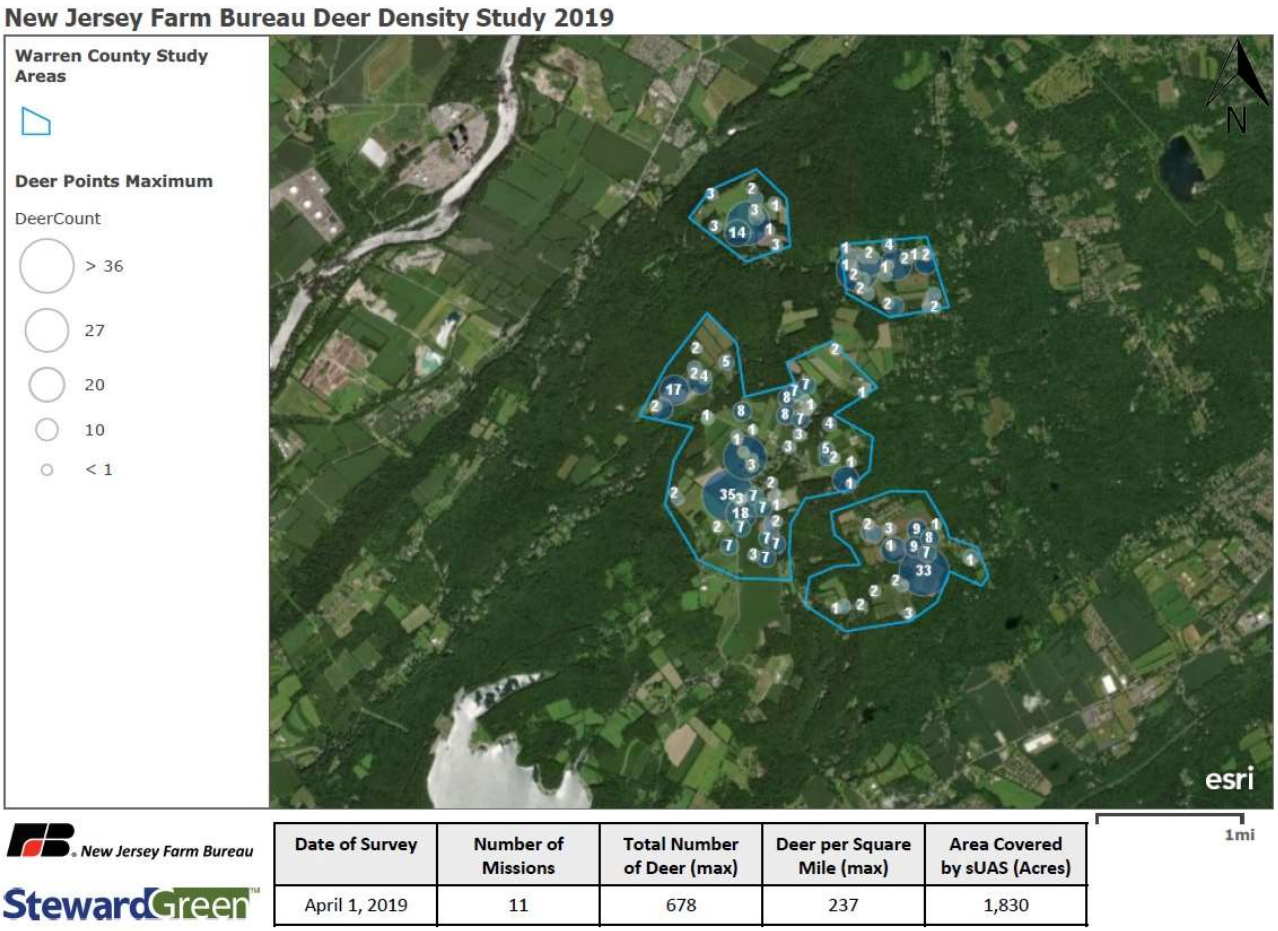
This information was then used to create geographic location maps with points of interest (the heat signatures of deer), mission and data information. Neighboring New Jersey open space properties were also located on the maps.

Results. At a minimum, there were 600 deer counted in the Warren County sampling areas, which equates to 210 deer per square mile for areas sampled in the data collection. At maximum, there were 678 deer counted in the sampling areas, equating to 237 deer per square mile. See Figures 7, 8, 9, 10, 11, 12 and Tables 1.

Table 1. **Deer Density- Maximum vs. Minimum, Warren County, NJ**

Warren County:					
	Acres	Deer Max	Max SM	Deer mir	Min SM
Area 1 Northwest	150	70	299	56	239
Area 2 Northeast	175	153	560	131	479
Area 3 West	1055	336	204	310	184
Area 4 South	450	119	169	103	146
Totals:	1830	678	237	600	210

Figure 7. **Warren County Maximum Population Density Map**.



Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 1, 2019	11	678	237	1,830

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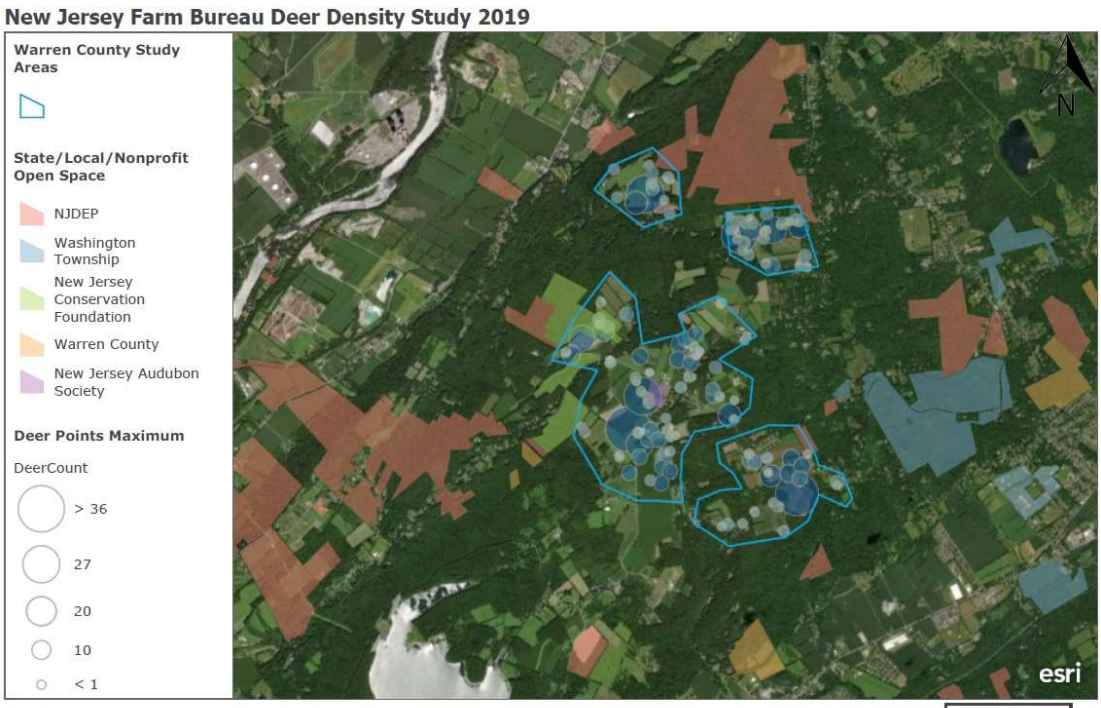
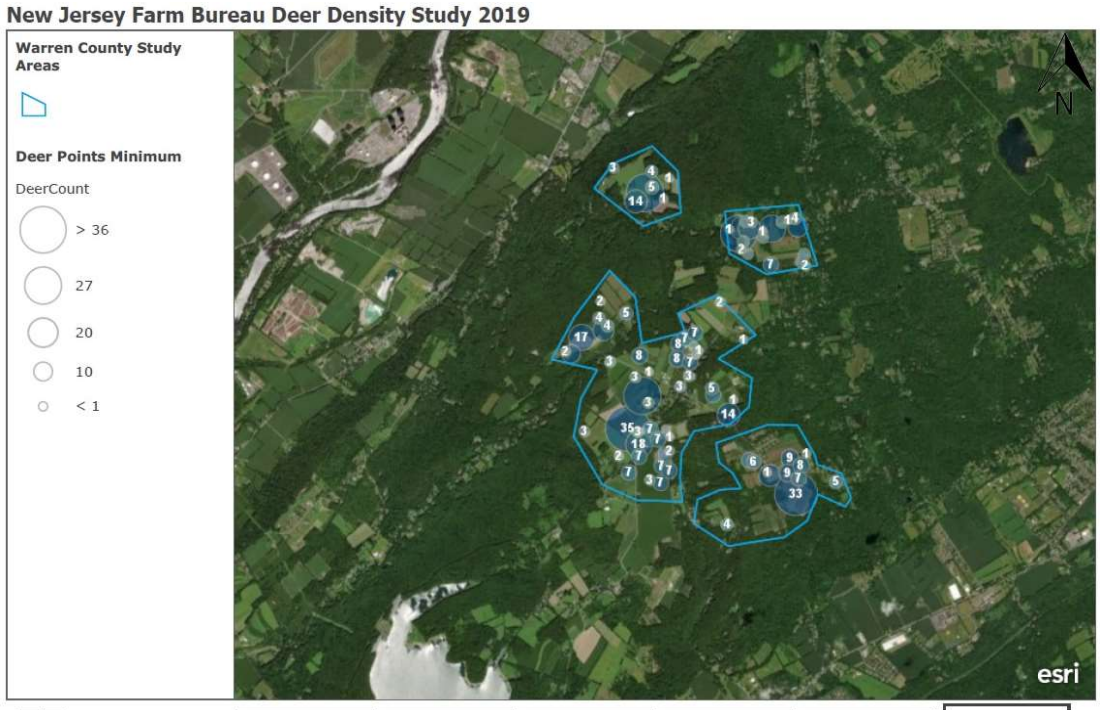
Figure 8. **Warren County Maximum Population Density Map with Open Space Identified**.



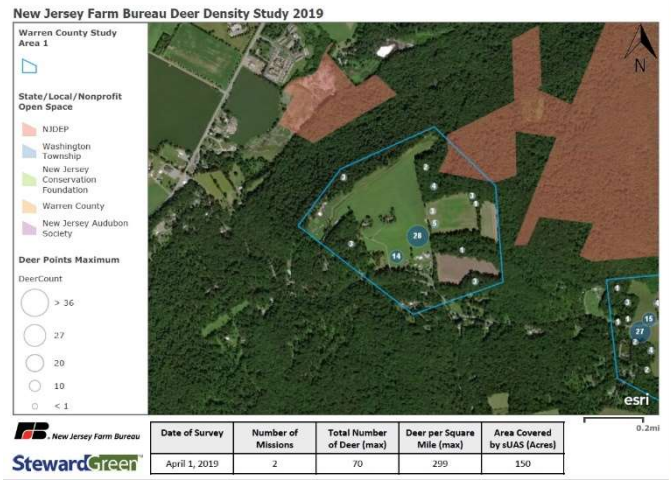
Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 1, 2019	11	678	237	1,830

Figure 9. **Warren County Minimum Population Density Map**.



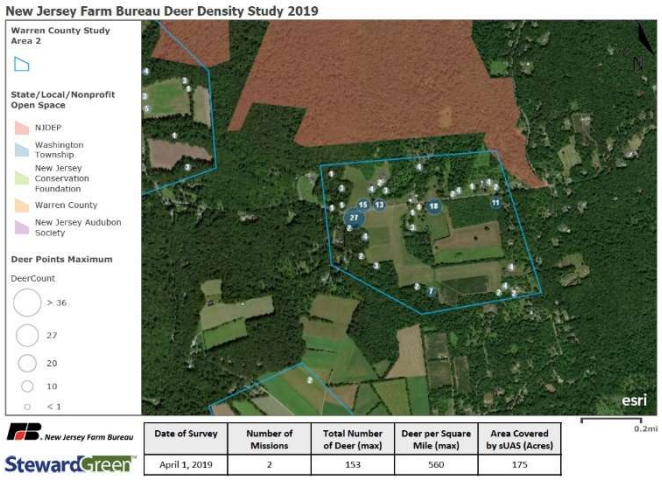
Date of Survey	Number of Missions	Total Number of Deer (min)	Deer per Square Mile (min)	Area Covered by sUAS (Acres)
April 1, 2019	11	594	208	1,830

Figure 10. **Warren County Area 1 Maximum Population Density Map**.



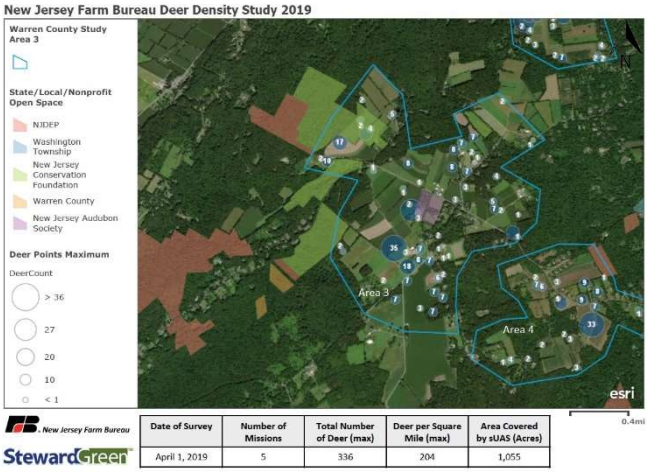
Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 1, 2019	2	70	299	150

Figure 11. **Warren County Area 2 Maximum Population Density Map**.



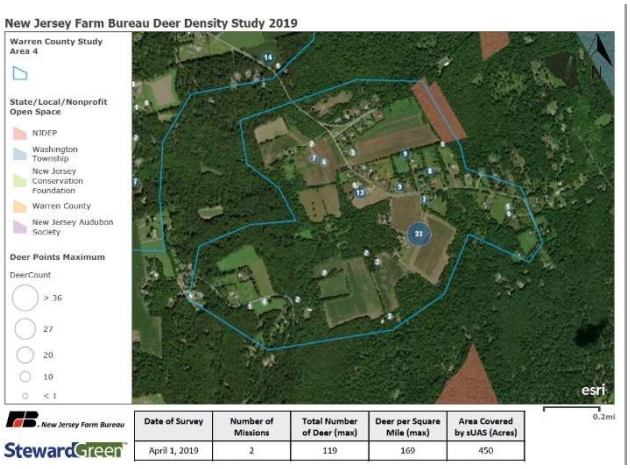
Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 1, 2019	2	153	560	175

Figure 12. **Warren County Area 3 Maximum Population Density Map**.



Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 1, 2019	5	336	204	1,055

Figure 13. **Warren County Area 4 Maximum Population Density Map**.



Date of Survey	Number of Missions	Total Number of Deer (max)	Deer per Square Mile (max)	Area Covered by sUAS (Acres)
April 1, 2019	2	119	169	450

-End of Appendix G-

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Steward Green LLC has been consulting clients for many years in conservation, wildlife habitat regeneration 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. Steward Green has also completed deer density surveys in New Jersey for the areas of Watchung, The Watershed Institute Preserve in Pennington, Raritan Township, Readington Township and Falls Brook.

Mapping. All maps throughout this report were created by Steward Green™ 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 Spring of 2019 using thermal imagery obtained by sUAS. Data was recorded in the field using the Collector for ArcGIS data collection application. Imagery was 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

Disclaimer: The maps representing open space data included in this report were developed using New Jersey Department of Environmental Protection Geographic Information System digital data, but this secondary product has not been verified by NJDEP and is not state authorized or endorsed.

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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