



White-tailed Deer Monitoring Protocol for the Heartland Inventory and Monitoring Network

Narrative, Version 2.0

Natural Resource Report NPS/HTLN/NRR—2018/1801



ON THE COVER

White-tailed deer at Wilson's Creek National Battlefield, Missouri
Photography by Heartland I&M Network, NPS

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Heartland Inventory and Monitoring Network (HTLN)

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Executive Summary

Because of their impacts on vegetation, disease transmission, visitor health, and vehicle-deer collisions, park managers at Arkansas Post National Memorial, Pea Ridge National Military Park, and Wilson's Creek National Battlefield identified white-tailed deer as a vital sign for monitoring (DeBacker et al. 2005). Monitoring white-tailed deer populations better positions park management to take action to mitigate concerns involving deer.

This monitoring protocol consists of a protocol narrative (this document) and 10 standard operating procedures (SOPs) for monitoring white-tailed deer in HTLN parks. The overall goals of HTLN white-tailed deer monitoring are to 1) document annual changes in the number of white-tailed deer, changes could signal presence of illegal deer harvest, disease, or other acute factors of concern for park management; 2) document long-term trends in the number of white-tailed deer to help park management determine if measures need to be taken to maintain herd health, minimize vegetation damage within a park, or alleviate visitor health concerns; and 3) annually map locations of white-tailed deer observed to assist park management in assessing the influences of management actions on deer usage of an area, habitat type, etc.

This protocol narrative describes the sampling design for white-tailed deer, including the response design (data collection methods), spatial design (the park and survey routes within a park), and revisit design (timing and frequency of visits survey routes). It also outlines field methods for establishing survey routes, counting deer, and measuring visible area. Details can be found in the SOPs, which are listed below and available at irma.nps.gov. Other aspects of the protocol summarized in the narrative include procedures for data management and reporting, personnel and operating requirements, and instructions for how to revise the protocol.

Acknowledgments

The National Park Service's Inventory and Monitoring Program provided funding for the development of this white-tailed deer monitoring protocol, and continue to fund monitoring of the resource in network parks. Numerous NPS personnel have contributed in-kind support to the development of this protocol, and continue to assist with annual surveys. We acknowledge important input from resource managers during a breakout session of the 2005 Heartland Inventory and Monitoring Network annual meeting to help refine the monitoring objectives. This protocol in its earlier version (Version 1.0) benefited from comments by Dr. Paul Lukacs, and peer review by Dr. Lynn Robbins, Dr. Jonathan Jenks, and Dr. David Leslie. This revised version was peer reviewed by Dr. Joe C. DeVivo, and Dr. Dan Licht.

Revision History Log

Revision history log

Prev. Version #	Revision Date	Author(s)	Changes Made	Reason for Change	New Version #
1.0	8/30/2018	DeBacker and Peitz	• The maximum number of weekly replicates per year was reduced from six (6) to four (4). • Rather than use the location of all deer seen over all survey nights to adjust the mapped visible area, a second round of visibility assessments was added to increase the resolution of the visible area estimate. • New analysis and reporting methods are included.	Changes were made to document improvements in sampling efficiency and data analysis, and changes in reporting requirements.	2.0

Version numbers increase incrementally by hundredths (e.g., version 1.01, version 1.02, etc.) for minor changes. Major revisions will be designated with the next whole number (e.g., version 2.0, 3.0, 4.0...). The previous version number, date of revision, author of the revision, and the reason for making the changes are recorded along with the new version number. The first version of this protocol was published in 2007.

List of Standard Operating Procedures (SOPs)

The following standard operating procedures (SOPs) are associated with this narrative. Each SOP is a stand-alone document and can be found at irma.nps.gov.

SOP 1. Before the Field Season

SOP 2. Training and Testing Observers

SOP 3. Establishing Survey Routes

SOP 4. Conducting the Spotlight Survey

SOP 5. Measuring Visible Area

SOP 6. Tabular and Spatial Data Management

SOP 7. Data Summary and Analysis

SOP 8. Reporting

SOP 9. Procedures and Equipment Storage after the Field Season

SOP 10. Revising the Protocol

Background and Objectives

Issue Being Addressed and Rationale for Monitoring White-tailed Deer Populations

Since European settlement, white-tailed deer (*Odocoileus virginianus*) populations in North America have experienced enormous changes in size and distribution. Once abundant, deer declined to near extinction by the early 1900s. Clearing of forested lands and unrestricted hunting contributed heavily to the decline of the species (Stoll and Donohoe 1973; Dennis 1983). Declines in the number of deer were especially prevalent in the East and Midwest sections of the country where large sections of the land were converted to row-crop farming.

Regulated white-tailed deer hunting and extermination of most of their natural predators has led to unprecedented population growth throughout their range. With natural deer habitat severely reduced, a variety of agricultural practices now provide artificial food sources for deer. The ability of white-tailed deer to adapt to human disturbance has also aided in the recovery of this species. Urban sprawl benefits deer by fragmenting continuous blocks of forested lands into small sections with increased edge habitat favored by deer and rarely available for hunting. Deer experience high rates of population growth in these small blocks of patchy habitat as long as food

is available. Grass and forb production is greater in these areas, as is mast production by oaks, hickories, and other trees when compared to larger blocks of forested land (Peitz et al. 2001). Urban sprawl also redistributes deer by eliminating habitat in one area, thereby concentrating deer in available habitat in another (Shafer-Nolan 1997).

Deer become vulnerable to overpopulation, disease, and starvation in the absence of natural predators and hunting (McGuinness 1997; Pletscher 1987; Potvin and Hout 1983). When deer occur in high densities, diseases are transmitted more readily. In years when forage or mast production is restricted due to climatic conditions, starvation or poor herd health can occur. High deer populations also contribute to over-browsing of vegetation, which leads to plant mortality, decreased plant reproduction, and may favor less preferred exotic species (McShea and Rappole 1997). This shift in species assemblages can reduce plant diversity at a local level and cause changes in the functioning of prairie and woodland communities. Rare and sensitive plant species may be influenced negatively by deer foraging, although the influence of deer on the status of most rare and sensitive plant species has received little study. Augustine and Frelich (1998), however, demonstrated deer foraging was detrimental to *Trillium* spp.



White-tailed deer at Pea Ridge National Military Park, Arkansas. NPS



Bedded down white-tailed deer at Wilson's Creek National Battlefield, Missouri. NPS

and Fletcher et al. (2001) found bellwort (*Uvularia* spp.) and false Solomon's seal (*Smilacina* spp.) were negatively impacted by deer foraging. Studies have shown that deer also have a negative effect on developing forestland (Crouch and Paulson 1968; Horsely and Marquis 1983; Marquis 1981; Rooney and Waller 2003). Browsing on young tree seedlings causes stunted growth as well as mortality (Michael 1992; Mladenoff and Stearns 1993; Rooney and Waller 2003). Research has shown that in some situations damage from deer, as well as mice and rabbits, may be a key impediment to forest restoration (Crouch and Paulson 1968; Strole and Anderson 1992).

White-tailed deer are often viewed as an important component of park ecosystems. Deer have a tremendous following among the public and many parks provide information on the status of deer through their interpretive programs. This information is generally anecdotal in nature, however. Another downside to high white-tailed deer populations in parks is that they can present a safety hazard to motorists and park visitors. High deer populations increase the number of vehicle-deer collisions that result in property damage and personal injuries (Bellis and Graves 1971; Carbaugh et al. 1975; Frazer 1979; Long et al. 2010; Ng et al. 2008; Waring et al. 1991). In some cases, vehicle-deer collisions can result in the loss of human life. Deer also disperse ticks that may carry Lyme disease (Connelly et al. 1987), a debilitating immune system illness

transmitted to humans by tick bites. Ticks carrying other diseases transmittable to humans, such as Rocky Mountain Spotted Fever and Ehrlichiosis, may be spread by deer as well. Information on trends in deer populations helps park managers determine if control measures are necessary to protect other park resources and improve visitor safety.

Against a backdrop of urban sprawl, altered ecosystems, and concerns over visitor safety on National Park Service lands, we proposed monitoring white-tailed deer populations. Documenting long-term patterns in the number of deer allows for evaluation of potential correlations with changes in vegetation (e.g., through restoration of the cultural landscape). With this information, resource managers can more effectively identify and potentially mitigate damage caused to vegetation communities and endangered plant populations by deer.

Monitoring trends in the abundance of white-tailed deer populations is critical to understanding herd health over the long-term (Gee et al. 1994). The impacts of deer on vegetation, disease transmission, visitor health, and vehicle-deer collisions can only be thoroughly assessed with a good knowledge of trends in population size. Monitoring deer populations may help protect ecosystem integrity, which is defined as the capability of an environment to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity,

and functional organization comparable to that of natural habitat of the region (Karr and Dudley 1981).

Historical Development of White-Tailed Deer Monitoring in Network Parks

Park managers at Arkansas Post National Memorial, Pea Ridge National Military Park, and Wilson's Creek National Battlefield identified deer as a vital sign for long-term monitoring (DeBacker et al. 2005). Pilot data collection began in March 2005 and data were analyzed using distance software (Buckland et al. 2001). Distance analysis adjusts density estimates to account for unobserved individuals. In May 2005, Dr. Paul Lukacs, then with the Inventory and Monitoring Division central office, reviewed preliminary results. Dr. Lukacs was critical of the use of distance analysis, noting two violations of underlying assumptions: 1) the tour road is not a random sample, and 2) the distribution of deer is influenced by the road (Supplement 1). Dr. Lukacs offered several alternatives including dropping deer as a vital sign.

At an annual meeting of the Heartland Network (HTLN) in August 2005, a break out session was devoted to determining if and how to move ahead with deer monitoring (see Supplement 2). Managers reiterated their need to know about trends in deer population size with regard to the impact of deer on vegetation, disease transmission, concern over vehicle-deer collisions in and around parks, and the impacts of deer on neighboring private lands. In the end, resource managers felt tracking an index of the number of deer through time was the most efficient and sustainable use of resources.

The first deer monitoring protocol was published in 2007 (Peitz et al. 2007). The protocol utilized evening spotlight surveys conducted from roads to obtain counts that were adjusted for the visible area. Surveys were conducted once per week over a six-week period.

This 2018 revision further refines and clarifies the protocol:

- The maximum number of weekly replicates per year is reduced from six (6) to four (4).

- Rather than use the location of all deer seen over all survey nights to adjust the mapped visible area, a second round of visibility assessments is added to increase the resolution of the visible area estimate.
- New analysis and reporting methods are included.

Measurable Objectives

1. Document annual changes in the number of white-tailed deer.

Justification: *Significant annual changes in the number of deer may signal the presence of illegal deer harvest, disease, or other acute factors of concern for park management.*

2. Determine long-term trends in the number of white-tailed deer.

Justification: *Understanding decadal trends in the number of deer will help park management determine if measures need to be taken to maintain herd health, minimize vegetation damage within a park, or alleviate visitor health concerns.*

3. Annually map locations of white-tailed deer observed.

Justification: *Mapping deer locations allows park management to assess the influences of management actions on deer usage of an area, habitat type, etc.*

Operational Objectives

1. Communicate monitoring results to park natural resource managers, other park staff, and partners, including outreach efforts when appropriate. Furthermore, contributions to the scientific community may be valuable.
2. Conduct monitoring safely, ideally without accident or injury. Safe monitoring includes during transportation to/from parks as well as during field operations.

Sampling Design

Monitored Populations

The populations of interest are the white-tailed deer herds within each park. In reality, observed deer may have home ranges that include regions outside of park boundaries. Thus, although sampling will be done entirely within park boundaries, we realize the deer herds in question may have more extensive ranges. For safety reasons, sampling will be done along existing park roads rather than random transects. The habitat types encountered along park roads were shown to be representative of habitat types in the overall parks (Sarah Wilkinson, personal communication). The type and distribution of habitats in the parks, however, may change over time. Therefore, habitat types encountered along park roads are not necessarily in proportion to the distribution of habitat types in the overall parks, and the location of park roads may affect the distribution of deer.

Sampling is limited to winter months, before spring green up (January through mid-February). The deer present at this time will influence herd size and subsequent impacts to park resources through the remainder of the year. In many situations, a knowledge of the buck:doe and fawn:doe ratios would be desirable. But most bucks will have shed their antlers by this time and fawns will be of sufficient size to be mistaken for older does. Therefore, buck:doe and fawn:doe ratios cannot be calculated. Overall herd density is best estimated during winter months, as declines in deer numbers through fawn mortality and hunting around park lands have stabilized. It is more desirable to have an estimate of herd densities on National Park Service lands than having information on sex and age ratios.

Spatial Design

Sampling locations or ‘routes’ are selected as described in SOP 3 “Establishing Survey Routes.” Maps showing the survey routes at Arkansas Post National Monument, Arkansas; Pea Ridge National Military Park, Arkansas; and Wilson’s Creek National Battlefield, Missouri are given in Figures 1–3.

Response Design

Spotlight surveys (repeated counts) commence one hour after official sunset and follow the predetermined survey routes described above. The number of deer observed in one pass along the survey route will constitute a “count.” The visible area along each survey route will also be estimated. The visible area represents the area over which deer should be seen if they are present (i.e., close enough to the road and not obscured by vegetation). An “adjusted count” will be calculated for each night by dividing the maximum count for that night by the visible area. Adjusted counts are reported as individuals per unit area, and although this represents a measure of density, it should not be confused with actual density, as we make no attempt to quantify home ranges of deer. Adjusted counts are used instead of raw counts in an attempt to reduce the most common sources of error associated with the spotlight method (see below).

Deer positions are recorded as distance and azimuth from the Global Navigation Satellite System (GNSS) location of the observation vehicle. The visible area is defined by taking measurements perpendicular to the sample route out to a distance beyond which deer are not visible. This area is determined at 0.16-km (0.1-mile) intervals along the survey route, immediately following deer counts on the first and third weekly replicates. The starting point of the second round of visibility estimates is 0.08 km (0.05 mile) from the starting point of the first round.

We assume the adjusted counts are positively correlated with true population density, but to an unknown degree. Although it is not possible to determine the true number of deer in a park at any time from these methods, information on relative abundance is of value in detecting trends. In a meeting regarding white-tailed deer monitoring held in 2005, resource managers from the representative parks indicated that determining absolute deer density in the parks was not a priority (see Supplement 2). Resource managers did desire information on changes in deer abundance over time, so that if white-tailed deer ever became an important management issue, a history of population trends would be available.

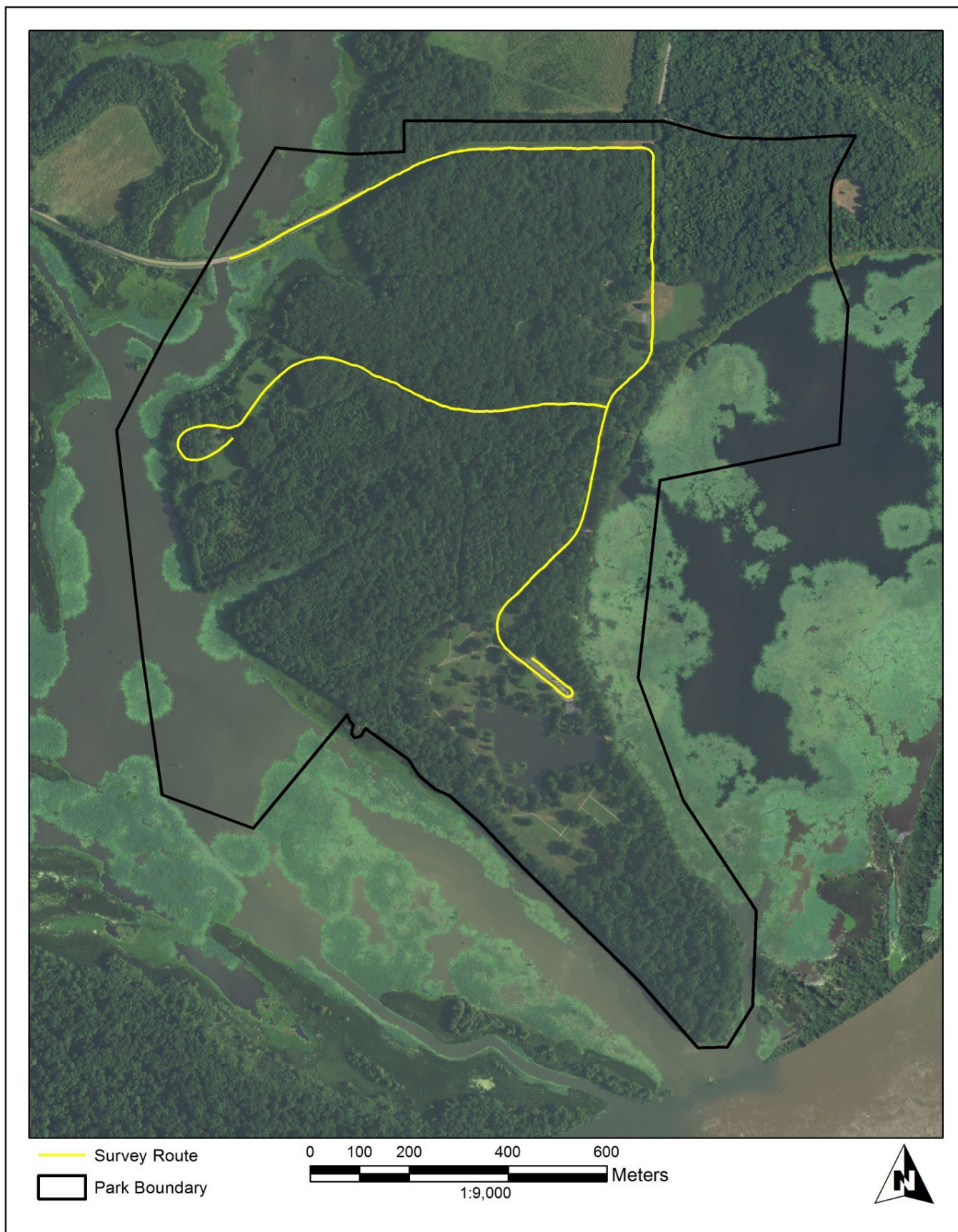


Figure 1. White-tailed deer survey route at Arkansas Post National Memorial, Arkansas.

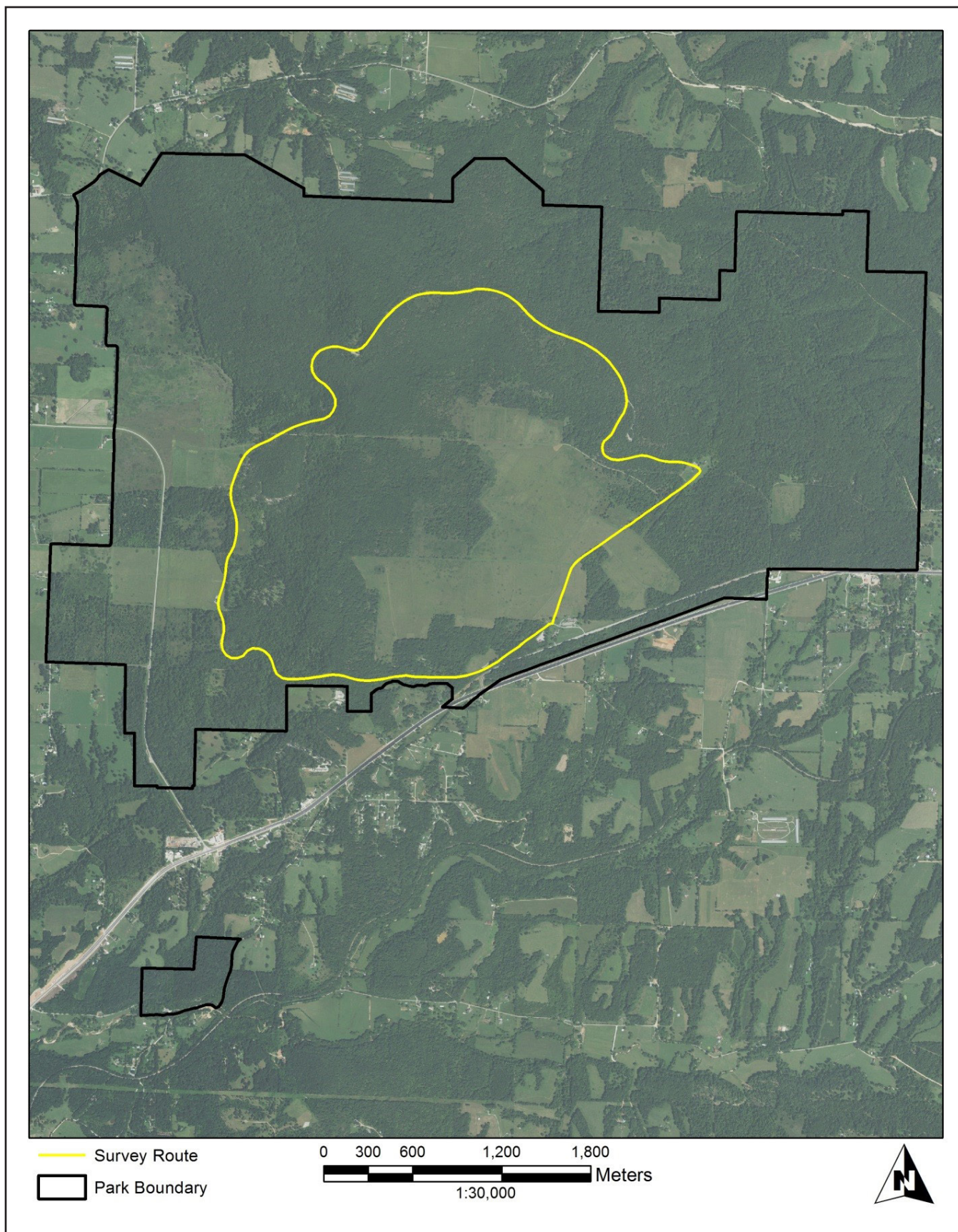


Figure 2. White-tailed deer survey route at Pea Ridge National Military Park, Arkansas.

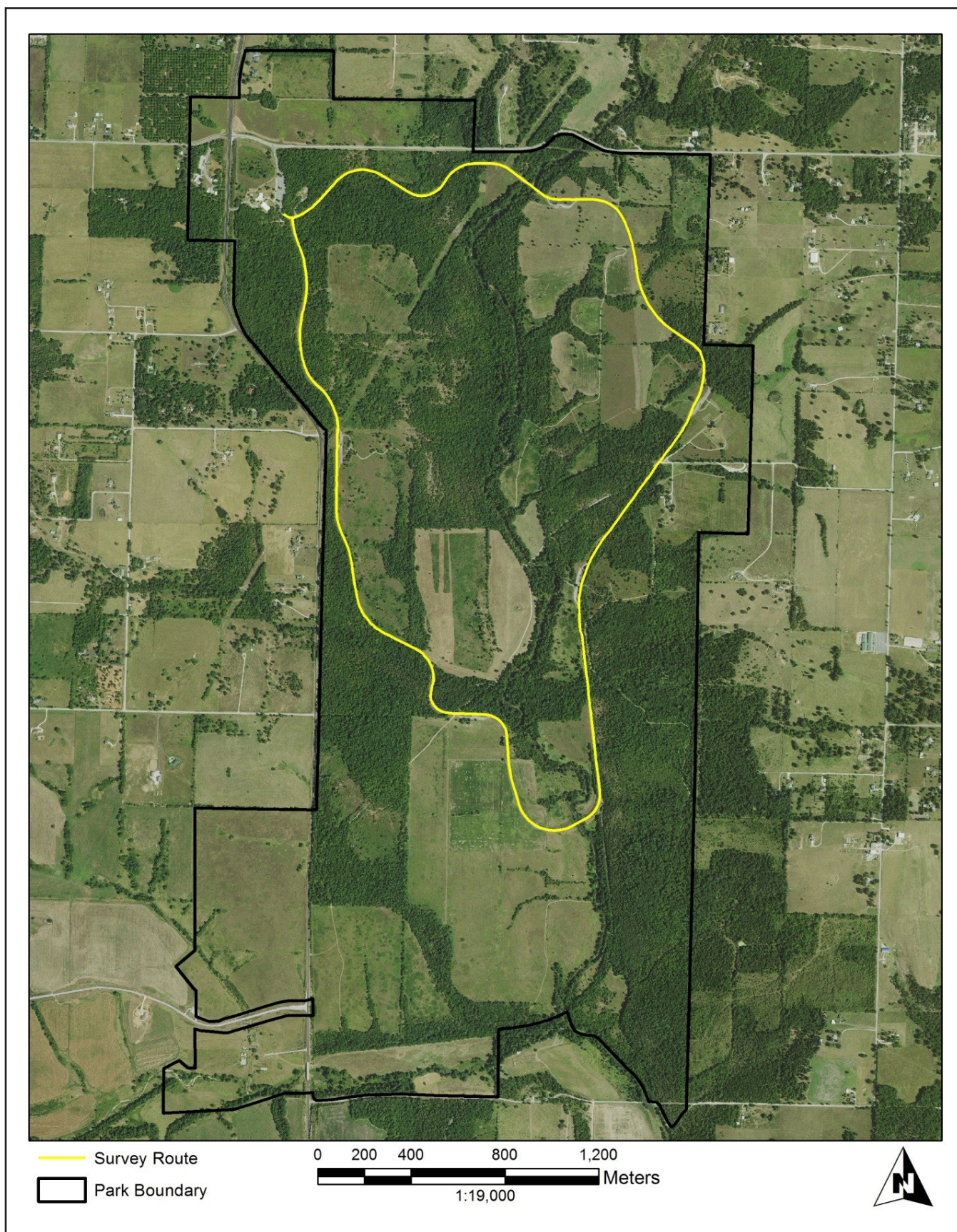


Figure 3. White-tailed deer survey route at Wilson's Creek National Battlefield, Missouri.

Revisit Design

Survey routes within each HTLN park unit monitored for white-tailed deer will be sampled annually. To obtain a measure of variability, surveys will be conducted on four different weekly replicates. The maximum count from repeated counts conducted each night will be used to calculate the adjusted count for that date. Assessments of visible area will be conducted on the first and third replicate nights to get an annual estimate of the area over which deer can be seen. Changing vegetation in each HTLN park requires that visibility estimates be made each year and that the area sampled is not predetermined from aerial photos or maps. Visibility assessments begin as soon as the second repeated count is completed.

Rationale for Selecting this Sampling Design over Others

Dozens of different monitoring programs utilizing a multitude of sampling approaches to determine local white-tailed deer population densities are currently in place throughout North America. Most common survey methods allow for population estimates, but no single method will adequately sample the complete population. The spotlight survey has been widely employed as a practical method for estimating trends in the deer population in an area. Sampling involves spotlighting deer at night to obtain some estimate of the number of deer present in an area and then determining the total area monitored during the survey. In practice, the method documented in this protocol is a variable width, belt transect estimate of the number of deer with width determined by the visible area. This is a slight modification of the Shult and Armstrong (1983) method in which the reference area is calculated by averaging visible area measurements taken at 0.1-mile intervals and multiplying that value by the length of the survey transect. The reference may include both visible and obstructed areas.

Aerial surveys, mark and recapture surveys, fecal pellet counts, the use of infrared triggered cameras, 'rushing,' and distance sampling are different types of deer survey methods that have been considered for use in estimating the size of white-tailed deer herds in HTLN parks. Camouflaging ground cover and limited visibility from the air inhibit accurate aerial surveys; furthermore aerial surveys are expensive to implement and require experienced observers (Bates 2004; Haroldson et al. 2003). Aerial surveys are difficult to arrange and generally require snow

on the ground during a survey to aid in locating and seeing deer, especially if deer are visually sighted. Infrared imaging from air or ground does not require visually spotting deer. However, skilled operators are required to effectively use the equipment and to differentiate between deer observations and those of other animals. Since HTLN parks are spread across the Midwest Region, numerous contracts with different agencies would have to be made to carry out such surveys.

The accuracy of a mark and recapture survey is dependent upon the number of deer marked and the number of deer resighted. Kilpatrick et al. (1997) calculated that it takes a minimum of 4.4 hours to capture and mark each deer. If just 10% of a herd as small as 100 individuals were marked, it would require at least 44 hours or one week to capture and mark deer. Herd sizes in HTLN parks are much larger than 100 individuals; thus the field hours to capture enough deer would be cost-prohibitive. The number of surveys required to obtain an adequate number of resighted individuals for an accurate estimate of the population could be cost prohibitive as well.

Fecal pellet counts along transect lines is a survey type that has been used for many years. These counts require many field hours to complete, however, and the cost associated with field hours required to complete a survey would be prohibitive. Another factor to consider with fecal pellet counts is that of logistics. A minimum of two multi-day trips would be required to each HTLN park unit to conduct a survey. The first trip is needed to clear areas of deer feces so an accurate time interval for pellet deposition can be determined. During the second trip, fecal pellet groups deposited since the first trip are counted. Fecal pellet counts are generally limiting with regards to the amount of area that can be covered because of the labor involved.

Remote cameras have been used to census white-tailed deer (Jacobson et al. 1997). This method is cost prohibitive as well. Initial camera cost and the annual cost for up keep and camera replacements would limit the scope of our deer monitoring to only the smallest HTLN parks. One camera per 20 ha (48 acres) was recommended for the National Capital Region Network (Bates 2004), for example. Using infrared cameras also requires a considerable amount of time for processing pictures, identifying

each deer, and determining accurate estimates of the population.

‘Rushing’ involves placing observers in hidden locations along a line on one end of a park. Another group starts on the opposite end of the park in an attempt to scare the deer so they run by the hidden observers who count their numbers. This type of survey is not possible given the size of most HTLN park units. Also, it may not be the best way to acquire accurate numbers of the deer population as individuals can be counted multiple times by different observers.

The distance method of sampling takes into account decreasing detection probabilities as distance from an observer increases. Densities of the target organism are calculated based on the shape of an empirically determined detection function (Buckland et al. 2001). This method was not employed because several assumptions may be violated (e.g., placement of transects is not random, locations of transects [roads] may affect the distribution of deer, etc.). See the critical comments of Dr. Paul Lukacs in Supplement 1 regarding this and other sampling options.

Limitations of this Sampling Design

Road-based spotlight surveys for deer monitoring have been increasingly criticized as research has demonstrated such surveys are biased due to nonrandom placement of roads and highly variable detection rates of observers (summarized in Collier et al. 2013). A study comparing spotlight survey data with data obtained from a thermal-imager found that detection probabilities during spotlight surveys ranged from 0 to 0.8 and concluded that the data collected from road-based spotlight surveys were “likely not reflective of the standing deer population” (Collier et al. 2013). Most deer missed by the spotlight surveys, however, were either too far for the spotlights to reach or were obstructed by heavy vegetation. Unfortunately, Collier et al. (2013) did

not quantify the magnitude of error due to these two sources versus others in their study. By annually determining the visible area and limiting observations to less than 250 m, this protocol attempts to exclude these two main sources of error. Thus we assume that the adjusted counts are positively related to deer abundances, although this has not been evaluated empirically.

The use of adjusted counts is a type of index method, in which the adjusted counts are a product of actual abundance and a detection probability. Such indices rely on the assumption that the number of individuals detected represents a proportion of the true population size, and this proportion remains constant over time. The validity of this assumption is questionable because many factors affect the detection probability, such as changing or different habitat and the use of different observers (e.g., Anderson 2001, 2003).

However, it has been argued that indices may be useful in monitoring situations when the change in population size is large relative to the variation in detectability and such variation is independent of population size (Thompson 2002; Johnson 2008). Indices may be most useful in “early warning monitoring systems,” when estimates of population change could be used as a basis for further study (Barker and Sauer 1995). Identifying and eliminating, or reducing to the extent possible, sources of error that result in a violation of the proportionality assumption will improve the utility of such indices. Annually estimating the visible area represents a way of accounting for changes in habitat over time. Additionally, training and evaluating observers helps reduce observer error and standardize detectability among observers (see Quality Assurance Plan for Monitoring White-tailed Deer in the Heartland Inventory and Monitoring Network [HTLN 2018]).

Field Methods

Field Season Preparations, Field Schedule, and Equipment Setup

Prior to the field season each year, usually beginning the previous November or December, all observers should review this entire protocol, and all associated standard operating procedures (SOPs). Observers should pay special attention to the tasks described in SOP 1 “Before the Field Season” and SOP 2 “Training and Testing Observers.” All observers must demonstrate proficiency in identifying deer and estimating distance by completing field training and testing as described in SOP 2. All of the equipment and supplies listed in SOP 1 should be organized and made ready for the field season; copies of the field data forms in SOP 4 “Conducting the Spotlight Survey” and SOP 5 “Measuring the Visible Area” should be made. Twenty-five percent of all field data sheets should be copied to write-in-the-rain paper if an open top survey vehicle is used.

Sampling dates should be scheduled and logistics organized prior to the start of each field season, with alternative sampling dates identified as well. Every year, at each park an effort should be made to survey deer weekly for four consecutive weeks (weekly replicates; Table 1; Supplement 3) starting in early January. Two repeated deer counts should be scheduled for completion during the first and third weekly replicate (Table 1). Three repeated deer counts should be scheduled for completion during the second and fourth weekly replicate (Table 1). Measurements of the visible area should be scheduled for the first and third weekly replicate, after two repeated count are completed. Staff workloads and unpredictable weather (e.g., the onset of extremely cold weather, periods of rain or snow, extreme icy conditions)

necessitate maintaining some flexibility when scheduling the sequence and duration of sampling trips.

Influences of weather on deer activity and detectability need to be considered during counts. During periods of high wind, deer move from open to closed areas (Linsdale and Tomich 1953; Loveless 1964; Ozoga and Gysel 1972; Beier and McCullough 1990). Therefore, repeated counts are restricted to periods without high winds (i.e., sustained winds >30 km/hr [18.6 mph]) to optimize seeing deer in open habitats with greater visibility. Although heavy rain does not influence deer activities (Michael 1970; Zagata and Haugen 1974; Beier and McCullough 1990), periods of heavy rain will influence visibility, and thus should be avoided. Likewise, snowfall greater than moderate will influence visibility, and thus should be avoided. Snow on the ground limits food availability, thus affecting patterns of deer movement as they seek out areas of higher food availability. Therefore, deer should not be surveyed during periods of significant snow accumulation as this will add unnecessary variability into count data across years. Weather criteria for conducting deer counts are outlined in SOP 1 “Before the Field Season.”

Sampling Methods

Permanent sampling routes, selected from existing all-weather roads within a park, are used to survey deer. Due to the nature and purpose of most parks, and for safety reasons, it is not recommended to drive off road to complete surveys. Once arriving at the park, park maps are used to familiarize each observer with the park, and determine starting point, direction, and order in which sections will be surveyed.

Table 1. Temporal sampling design for white-tailed deer monitoring. X = occurrence of repeated deer count; VA = visible area is assessed rather than a third repeated deer count.

Repeated Counts	Weekly Replicates			
	Week 1	Week 2	Week 3	Week 4
1	X	X	X	X
2	X	X	X	X
3	VA	X	VA	X



During spotlight surveys, many deer are seen at a distance and are only visible because of the reflection of light from the tapetum lucidum in their eyes. NPS

Each day the project manager splits the observation team into a pair of deer observers, a data recorder, and a driver. The data recorder is responsible for ensuring all data fields listed on the data dictionary of the GNSS unit are filled in and the location of each deer or deer group is recorded. The data recorder also fills out a paper copy of all data observations. Deer observers are responsible for locating deer and accurately taking distance measures from the survey vehicle to the deer or deer group. Observers are also responsible for measuring the angle of the deer or deer group from the survey vehicle and identifying the habitat type the deer or group is in. One observer, generally the project leader, takes all weather measurements. For safety reasons the driver should just drive and not be involved with the collection and recording of data.

Each member of the sampling team is responsible for keeping track of their equipment and data sheets. Before leaving the field each night, all equipment must be accounted for and data sheets must be checked for completeness and passed on to the project manager. The project manager is responsible for the safekeeping and organization of the data sheets and ensuring data entry. The data recorder is responsible for downloading all data from the GNSS unit. At the end of each year's sampling, a trip report including weather conditions, logistical problems, any

subsequent departure from the protocol, etc. should be written by the project manager.

Conducting the Spotlight Survey

Spotlight surveys will be used to obtain counts of white-tailed deer at each HTLN park unit. Methods for conducting the spotlight survey are given in SOP 4 "Conducting the Spotlight Survey" and are summarized here. Surveys are conducted from a survey vehicle moving no more than 16 km/hr (10 mph) using two 1,000,000 candlepower or greater spotlights. All deer seen along the survey route are counted and their locations are recorded using GNSS technologies.

Deer counts are made by two observers, one seated on the left and one on the right side of the vehicle. Distances from the stopped survey vehicle to all deer are determined with a rangefinder. Deer are usually observed in groups, in which case distance is taken to the center-most deer in the group. To map locations of deer, the direction and angle of all deer or deer groups from the survey vehicle are recorded as well.

From pilot data and subsequent surveys, it was observed that the highest number of deer counted each night generally occurred within the first couple of hours following official sunset (Supplement 4). However, on occasion, the maximum number of deer

counted occurred in the second or third repeated count. Therefore, two repeated counts commencing one hour after official sunset will be used to count deer numbers during the first and third weekly replicate to accommodate time needed to estimate the visible area (Table 1). Three repeated counts commencing one hour after official sunset will be used to count deer numbers during the second and fourth weekly replicates (Table 1). Jester and Dillard (2001) and Shult and Armstrong (1983) recommend starting surveys forty-five minutes to one hour after official sunset to maximize deer observed.

Measuring the Visible Area During Surveys

Determining the visible area is critical for adjusting counts. SOP 5 “Measuring the Visible Area” gives a detailed description of how the visible area during surveys is determined; a brief summary is presented here. Measurements of the visible area are taken on the first and third weekly replicate after the repeated counts are completed by using a range finder to record the perpendicular distances from the survey vehicle to a point beyond which deer would not be visible. Measurements are taken every 0.16 km (0.1 miles) along the survey route. The starting point of the second round of measurements is 0.08 km (0.05 miles) from the starting point of the first round. The location of each perpendicular measure is marked using GNSS technologies. In an attempt to get a more robust picture of how much area is being surveyed along the route, the location of the survey vehicle should be adjusted slightly if objects are encountered

that block the true area observed during a survey. For example, if the view of an open field is blocked by a single cedar tree in the ditch next to the survey vehicle, move the vehicle forward or backward to see the field. Following procedures in SOP 7 “Data Summary and Analysis,” perpendicular distances are plotted on a map, a polygon is created, and the visible area is determined.

Annual visible areas, by definition, should include all deer observations. Deer may be observed at distances beyond the estimated visible area, however, indicating that either the visible area was underestimated at these points, or that the polygons were too coarse to take into account the fine scale differences in actual visibility. Adjusting the visible area to include all deer seen during surveys adds, on average, 15% to the overall visible area, and 40 to 60 additional hours of data processing time to the project (Supplement 5). Conducting two rounds of visibility estimates compared to one yields a finer scale estimate of visible area without adding significantly to the data collection and processing efforts.

Following procedures in SOP 7 “Data Summary and Analysis,” maps depicting the locations of deer during the monitoring period will be produced. These maps are intended to provide a “snapshot” of deer locations at the time of the survey. White-tailed deer have home ranges of 50 ha or more, and thus the individuals observed during the surveys may range across much of the park and outside park boundaries. Thus the maps should not be used for spatial inferences regarding the deer population.

Data Management

Data management procedures are an important part of any long-term monitoring program in that they provide data consistency, data security, and availability over time. Therefore, care must be taken to ensure that adequate time and personnel are available for accurate data recording, data entry and verification, and analysis.

Data processing typically involves the following steps: data entry, data verification, data validation, and backups/storage (see SOP 6 for details on each step). Data entry consists of transferring field data from field sheets into a monitoring database using data-entry forms. Data verification immediately follows data entry and involves checking the accuracy of computerized records against the original source, usually paper field records. Validation procedures seek to identify generic errors, such as missing, mismatched, or duplicate records, as well as logical errors specific to particular projects. Spatial validation of location coordinates can be accomplished using GIS. Global Positioning System (GPS) points are validated against DRGs (digital raster graphic files) or DOQQs (digital ortho-quarter quadrangles) for their general location.

Overview of Database Design

There are two databases for the white-tailed deer project. One is a tabular Microsoft Access database, which henceforth will be referred to as the database. The database houses the core data including sampling periods, sampling events, weather, the repeated counts, and total visible area. The database also documents the protocol version and QA/QC results. The other is an ESRI ArcGIS file geodatabase, which henceforth will be referred to as the geodatabase. The geodatabase houses all the spatial data associated with the project. This includes the individual visible area measurements, deer locations, deer offset locations, and habitat data. All data in the database and geodatabase can be linked together by using primary key fields such as EventID and DeerID.

Quality Assurance and Quality Control

Quality Assurance (QA) includes all activities designed to ensure that data, products, or services meet specified requirements. Quality Assurance focuses on building-in quality to prevent defects.

Quality Control (QC) includes procedures for checking whether data meet standards and annotating or qualifying data that do not (DeVivo 2016).

Quality Assurance (QA) and Quality Control (QC) procedures and design elements occur throughout data collection, processing, and reporting. The Quality Assurance Plan for Monitoring White-tailed Deer in the Heartland Network (HTLN 2018) fully describes all QA and QC elements for this protocol.

The database design includes fields to document the completion and results of QA/QC procedures and assessments.

- The Inventory and Monitoring Division Database Standards (Frakes et al. 2015) requires every datum to be unambiguously traceable to a specific version of a monitoring protocol, a quality assurance plan (QAP) where available, and a suite of standard operating procedures (SOPs).
- The certification guidelines for I&M data products (NPS 2016), and Minimum Implementation Standards for Network Projects v. 3.0 (Frakes and Kingston 2017) call for every datum to have an associated QA/QC processing level (e.g., raw, provisional, certified).
- An annual operational review is required for all active monitoring protocols (Mitchell et al. 2018). Completion of an operational review, a summary of any flagged data, and a link to the review report are stored in the monitoring database.

Metadata Procedures

The Federal Geographic Data Committee (FGDC) now provides a range of options as guidance for metadata of spatial and non-spatial federal agency data. Most recommendations are variations of the ISO191xx standard which is typically used for natural resource datasets. Creation of ISO metadata has been greatly facilitated by ESRI ArcGIS utilities that automatically generate spatial metadata. Once metadata are created, they should be saved in XML format following ISO metadata standards. Metadata are archived in the geodatabase and by WASO I&M (IRMA). Metadata are archived by WASO with the submission of the monitoring protocol and should be updated with each protocol revision.

Data Archival Procedures

HTLN archives all spatial and non-spatial data (including tabular documents) on a weekly basis. Backups are incremental rather than mirrored so that files are never overwritten. Permanent data archives are created on a quarterly and annual basis and stored offsite in a bank safe-box.

Like other monitoring databases/geodatabases, the white-tailed deer monitoring database and geodatabase are secured by file archives stored on the server. The databases are maintained under a directory called DeerSurveys under the heartlandcommon

production drive. The database immediately below this directory is the production copy of the database. Under DeerSurveys, there is also a subdirectory called “dev” that is short for “development.” All backups and earlier versions are stored under this directory.

Annually, in fulfillment of the Data Analysis and Reporting Requirements (Gallo, K. memorandum dated 4/23/2018), the dataset will be uploaded to IRMA DataStore. The dataset is flagged as “read only” for all users except the Project Leader and Data Manager.

Data Summary, Analysis, and Reporting

A critical component of any long-term monitoring protocol is a consistent and systematic way of analyzing and reporting on information (data) collected. The variable selected for data summary purposes is the adjusted count. This variable provides information to park managers on trends in park deer populations and may provide feedback on the effects of implemented management efforts (e.g., population control or vegetation restoration efforts). SOP 7 “Data Summary and Analysis” gives step-by-step details on how to 1) determine adjusted counts, 2) calculate an annual mean adjusted count and 95% confidence interval, and 3) determine percent annual deviation from long-term means in adjusted counts. Adjusted counts should be compared against previous estimates every year surveys are completed.

Adjusted Counts

During each weekly replicate, two or three repeated counts of deer will be obtained from the spotlight surveys. To calculate adjusted counts, the maximum count for each weekly replicate is divided by the visible area. Thus only one adjusted count is obtained for each weekly replicate. The visible area for each year will be the same for all calculations of adjusted counts. An estimate of the average annual adjusted count and corresponding 95% confidence interval are determined from weekly adjusted counts. The percent deviation from the long-term mean in annual adjusted counts should be calculated and reported annually. The range in adjusted counts each year can be determined from adjusted counts for weekly replicates as well.

Recommendations for Long-term Trend Analyses

An underlying purpose of the HTLN is to design and implement long-term ecological monitoring to evaluate the integrity of park ecosystems and contribute

to the understanding of ecosystem processes. The approach towards long-term analysis of monitoring data is therefore critical in meeting this goal. Graphs of the data through time with an estimate of uncertainty (95% confidence interval) should always be presented. Graphs are easily interpretable, and, as such, serve as useful tools for interpreting monitoring results to managers. Patterns are easily inferred from graphical presentation, and the likelihood that an observed trend is biologically important, as opposed to statistically significant, can often be more readily determined from graphs than tests of statistical inference.

A more rigorous statistical analysis of trends will be obtained by regressing adjusted counts against survey years. To accomplish this we will employ the computer software TRIM (Trends and Indices for Monitoring Data; Pannekoek and Van Strien 2004). TRIM is based on a loglinear model using generalized estimating equations, which allows temporal autocorrelation to be taken into account.

Reporting

Annual reporting updates should be completed by September 1st of the year data are collected. Annual reporting requirements include an informal trip report, an operational review report, and an annual update. The updates may be in the form of a resource brief, web article, or data visualizer. Trend reports are updated every three years. Trend reports explore correlations between annual adjusted counts and variables such as regional hunting harvest records, outbreaks of disease, or changes in vegetation. Trend reports are published as Natural Resource Reports in the NPS Natural Resource Reporting Series and uploaded to IRMA.

Personnel Requirements and Training

Roles and Responsibilities

The project manager is the lead ecologist for implementing this monitoring protocol, and is supervised by the Program Manager for HTLN. The data management aspect of the monitoring effort is the shared responsibility of the project manager, the GIS specialist, and the data manager. Typically, the project manager and GIS specialist are responsible for data collection and database design. The project manager is responsible for data entry, data verification, and data validation, as well as data summary, analysis, and reporting. The data manager is responsible for data archiving, data security, and data dissemination. The data manager, in collaboration with the project manager and GIS specialist, develops data entry forms and other database features as part of quality assurance, and automates report generation. The data manager is ultimately responsible for assuring that adequate QA/QC procedures are built into the database management system and appropriate data handling procedures are followed.

Qualifications and Training

The most essential component for the collection of credible, high-quality data is competent observers. The quality of the observer will determine the quality of the data. Therefore, all individuals will meet data quality standards as outlined in the “Quality Assurance Plan for Monitoring White-tailed Deer in the Heartland Inventory and Monitoring Network” document (HTLN 2018) prior to surveying deer.

Good night vision is a critical requirement as well. Many deer are seen at a distance and are only visible because of the reflection of light from the tapetum lucidum in their eyes. As well as being able to visually identify deer, observers should be tested frequently on their ability to estimate distances and measure them using a laser rangefinder. Although rangefinders are used extensively, time should be invested



Reflectors are used to help train field technicians. They simulate the reflective eyes of deer during practice spotlight surveys. NPS

in training personnel to estimate the distance from themselves to deer within different habitats to insure that all distance readings are taken from the observer to the deer and not to some object located between the observer and the deer. This will require training in the field (see SOP 2 “Training and Testing Observers”) to become proficient with the use of a laser rangefinder and to gain experience with estimating distances in different habitat types.

Operational Requirements

Field Schedule

White-tailed deer surveys will begin no sooner than the first week of January and generally end no later than the last full week of February, a period that coincides with peak visibility through brush and trees. Inclement weather and personnel workloads will preclude the scheduling of sampling events to specific annual dates. Deer surveys may be scheduled during early March if cold winter weather is unusually late in the year and spring green-up has not commenced.

Facility and Equipment Needs

The nature of deer survey work does not require special facilities beyond normal office space and equipment storage needs. Table 1.01 of SOP 1 “Before the Field Season” lists the field equipment needs for one crew. If two or more crews work simultaneously, equipment requirements will increase accordingly. Network vehicles are shared and fuel/maintenance costs are incurred at the Network level. Costs include the purchase of equipment and supplies listed in SOP 1, as well as maintenance and or replacement of equipment shared among multiple projects (e.g. GPS units, cameras, vehicles, server).

Budget Consideration

Four weeks are required to complete deer monitoring, including travel, in the three parks involved in the study (Arkansas Post National Monument, Pea

Ridge National Military Park, and Wilson’s Creek National Battlefield). Personnel expenses for field-work are based on a crew size of four people: ecologist (project leader), GIS specialist, one seasonal biological science technician, and a driver (usually, but not always supplied by the park). Field costs will vary from year to year depending on the skill level and training required to adequately prepare the seasonal biological technician for surveying deer (usually three nights at Wilson’s Creek National Battlefield). Data management personnel expenses include staff time of GIS specialist, project leader, and data leader. The project leader also invests time in preparation for field trips and data evaluation and reporting. These steps can include a month or more of the project leader’s time per report, not including peer reviewer’s time. Additional shared support staff includes the Quantitative Ecologist.

Procedure for Revising the Protocol and Archiving Previous Versions

Over time, revisions to both the protocol narrative and to specific SOPs are to be expected. Careful documentation of changes to the protocol, and a library of previous protocol versions are essential for maintaining consistency in data collection and for appropriate treatment of the data during data summary and analysis. Mitchell et al. (2018) describe the necessary review and documentation for modifying the monitoring protocol (SOP 10).

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Supplement 1. Monitoring Options

Options available for white-tailed deer monitoring

The following comments and recommendations were important in the development of the original, 2007 protocol. It is provided here for historical context and as evidence for changes to the protocol over its lifetime.

To: Heartland Network Inventory and Monitoring Program

From: Paul M. Lukacs

Re: Options available for white-tailed deer monitoring

Date: May 2, 2005

Several options exist for ways to monitoring white-tailed deer abundance on National Park Service land within the Heartland Network. I will outline the pros and cons of four potential options for monitoring deer. I have listed the options we discussed during our April 26-28 meeting below.

1. Discontinue deer abundance monitoring and reallocate money elsewhere.
2. Use remote cameras as a means of collecting point transect distance sampling data.
3. Use mark-resight methods to estimate abundance.
4. Continue with the current road-based distance sampling surveys with minor modifications.

The first option is to discontinue the white-tailed deer surveys and use the money spent on these surveys elsewhere. The rationale for this option is based on the value of an estimate of deer abundance for the management of NPS lands given the small size of the properties in consideration. If we assume that the exact number of deer on a property is known at a point in time, how would we use that information for the management of deer? The management questions at hand include 1) how frequently do deer move off the park and onto neighboring private property and 2) is the deer population over-abundant and causing impacts on rare plants from feeding or trampling? Even if we knew the abundance of deer on a park exactly, that does not tell us how often deer are moving off the park nor what the deer do while they are off of the NPS property. It would require a telemetry study to obtain the information needed to answer that management question. On the same note, if we knew exactly how many deer were on a park; that would not provide information about how they are impacting rare plants. A study directly examining deer-plant interactions would be needed to answer that question. Therefore, it seems that monitoring deer abundance is not going to address the management issues at hand. This does not suggest that all studies of deer are not useful; I am merely suggesting that deer abundance is not the parameter that will help answer these questions. Based on this reasoning, I recommend discontinuing the deer abundance monitoring.

The second option is to use remote digital cameras to obtain distance sampling data. For this option, digital cameras would be set out at random locations throughout a park. A timer would be set to take a picture at set intervals throughout dawn and dusk. Flagging would mark distance bands out from each camera. The pictures would be reviewed and deer detected and there distances would be recorded. The data would be analyzed in a distance sampling framework to estimate deer density and abundance. This is a statistically valid method for obtaining a park-wide estimate of abundance. Potential problems with this method are 1) the initial cost of purchasing cameras which may be high; 2) image resolution may not be high enough to effectively detect deer; and 3) it is not known what the encounter rate will be at each camera. Approximately 60-80 detections of deer would be needed to obtain a reliable estimate of detection probability. An additional advantage of using remote cameras is the cameras could be used for more than just the deer surveys, thus defraying the initial investment.

The third option uses mark-resight techniques to estimate abundance of deer on each NPS property. This option requires that some deer be marked at each park. Deer would be captured by drop net and uniquely marked with a tag that could be read with binoculars or spotting scope. Marked deer are released. Surveys are conducted and the numbers of marked and unmarked deer are recorded along with the identification of marks if possible. The bulk of the surveys would be done from the tour road and a lesser effort would be done by walking through the unroaded portions of the park.

The amount of effort required and expected precision of the abundance estimate varies by the proportion of the deer population marked and the number of resighting surveys conducted. I will develop some estimates of effort and precision based on past deer surveys. At WICR, the estimated deer abundance is 312 individuals (SE=142). I will base the exploration of effort on the estimate of 312 deer. During a single night of the deer surveys approximately 100 deer or 30 percent of the population are seen each night. Therefore, I will define a resighting occasion as equal to the effort put into 3 trips around the tour road. I estimated the expected standard error from resighting effort ranging from 3-9 nights and number of marks in the population ranging from 30-90, representing marking between 10 and 30% of the population. The results of the exploration are given in Table S1-1.

Table S1-1. Expected standard errors for estimated abundance from a mark-resight survey at WICR.

Number marked	Resighting Occasions			
	3	5	7	9
30	52	38	32	28
60	32	25	20	18
90	24	18	15	14

As expected, standard error decreases with increasing effort. Standard error decreases more rapidly as the number of individuals marked increases, but the cost of marking individuals is likely to be greater than the cost of adding more resighting occasions. It should be noted that a standard error of 52 with an estimate of abundance of 312 yields a coefficient of variation of 17%. This is likely to be sufficiently precise to obtain a good estimate of trend in abundance after several years of data have been collected.

Several potential problems exist for mark-resight surveys. First, if movement rates of deer are relatively high, it is possible that many of the marked deer could leave the park and be unavailable for sampling. If this is the case, some deer would need to be fit with radio-collars to estimate the rate at which deer are moving. Second, marking deer is invasive. It is possible for deer to be injured or killed during tagging. Moreover, tags will be visible to park visitors and employees. Finally, marking deer is an expensive endeavor. Thus, while mark-resight methods can produce good estimates of abundance, it is not without its limitations.

It has been suggested to maintain the road-based distance sampling surveys during the resighting occasions. I do not recommend this for reasons beyond the inadequacy of road-based distance sampling. When searching for deer for a mark-resight survey, you want to maximize the number of deer detected regardless of their location. When surveying with distance sampling you want to be absolutely sure to see all deer along the transect prior to any movement. Thus, observers may be more likely to spend additional time search for deer away from the especially as they try to read tag numbers and therefore miss deer along the road or not see them until after they moved. Combining the mark-resight and distance sampling surveys would likely detract from both methods.

The fourth option is to continue the current road-based distance sampling with slight modifications to improve detection prior to movement. This method has only one advantage, namely it is cheap. There are numerous problems with road-based distance sampling. First, using roads as the sampling frame limits inference to the roads, so any inference to the entire park is by strong assumption only. Second, roads follow patterns in the

geography of the park. This induces a correlation between the distribution of the transect and the distribution of the deer. This can cause the detection function to be invalid. When transects are not randomly placed, one must assume the deer are uniformly distributed with respect to the transect. We know this assumption will be false. Third, deer are rarely exactly on the road, therefore too few detections occur at zero distance. This makes fitting a detection function particularly difficult. We saw these problems expressed in the overview of the HTLN deer data at WICR and PERI. For these reasons, I simply cannot recommend continuing road-based distance sampling. While the road-based distance sampling is cheap, it is not useful.

Supplement 2. White-tailed Deer Meeting Notes

Notes from the white-tailed deer breakout session, 3 August 2005, Hopewell Culture NHP

The following comments and recommendations were important in the development of the original, 2007 protocol. It is provided here for historical context and as evidence for changes to the protocol over its lifetime.

Notes from white-tailed deer breakout session

3 August 2005

Hopewell Culture NHP

Attendees: David Peitz (WICR), Gary Sullivan (WICR), Kevin Eads (PERI), Lisa Petit (CUVA), Kevin Skerl (CUVA), Jesse Bolli (HOME), Tim Breen (OZAR), Lloyd Morrison (WICR).

At HTLN parks where white-tailed deer have been designated as vital signs, the following issues associated with white-tailed deer were identified as important to park managers:

- (1) General herd health and appearance.
- (2) Collisions with vehicles on roads within and adjacent to park boundaries.
- (3) Impacts on neighboring private lands (e.g., browsing in gardens, etc.), particularly as development increases in areas near parks.
- (4) Impacts on park resources.

Discussion of these issues yielded the following insights:

- (1) Lisa Petit, who is actively involved with deer management attempts at CUVA, stated that maintenance of herd health is not a sufficient reason for lethal removal of deer. Exceptions would be if deer exhibit signs of chronic wasting disease, high tick loads that could represent an increased threat of tick-borne diseases to humans, etc.
- (2) Similarly, activities of deer on adjacent lands outside the parks are not sufficient reasons for managing deer populations within the parks.
- (3) In general, there was low interest in obtaining data on movement of deer across park boundaries, or studying effects of deer outside the parks. Some limited radio-collar data has indicated that the majority of deer observed did not leave the park.
- (4) No park manager was concerned about the current impact of deer on specific park resources.
- (5) All park managers, however, were concerned that deer may have substantial impacts on park resources in the future, especially if they become more abundant, and that data on population trends over time would be very useful. Lisa Petit and Kevin Skerl suggested that the deer abundance issue at western parks in the network is analogous to the situation at CUVA (where deer are now a major problem) 25 years ago.

The possibility of dropping deer as a vital sign was raised, but there was little support for this. Most were of the opinion that vital signs should not be changed at this point.

There was a discussion of the different methods of estimating deer abundance, the problems associated with the distance method, and what methods other state and federal agencies were using. It was explained that a variety of methods may be used to estimate deer abundance, and some are more accurate than others; the more accurate methods require greater expenditures of time and effort. There was a discussion of what sort of burden of proof would be required in different types of circumstances, and an explanation of how the I&M program was

attempting to “raise the bar” on the caliber of scientific work done in the parks. Lisa Petit and Kevin Skerl noted that if data are ever to be presented in a court of law, these data should be derived from widely used and accepted methods. It was pointed out that some methodologies currently in use are much more accurate than others.

The issue of how much our network could afford to invest in deer monitoring was raised, but no one present could definitively answer this question. The consensus of the managers was basically that *we should give them the best data we could with the resources available*.

There was a discussion of how to monitor impacts, and it was decided that conducting enclosure experiments was the best way to do this, although no one desired such information immediately. It was disclosed that ARPO and PERI have existing deer enclosures, and such enclosures also exist at the Springfield Nature Center, near WICR. It was pointed out that our network may not be able to increase the time and money spent on deer monitoring to conduct such experiments in the future. The managers seemed to think they could obtain resources from other sources or attract outside cooperators to conduct enclosure experiments, if necessary, although they deemed it very important to have background data on deer abundance trends to document any increases in the deer population.

The most important conclusions from this session were:

- (1) Park managers are not so much concerned with absolute deer abundance in the parks as they are with changes in the relative abundance over time.
- (2) Park managers, although concerned with the impacts of deer outside the park, felt such impacts were not the park’s problem nor were such impacts sufficient for management of deer populations by lethal removal within the park.
- (3) Park managers are more concerned about future potential impacts of white-tailed deer on park resources than any current impacts.

The following recommendations follow from this discussion:

- (1) Continue monitoring white-tailed deer with similar methods as were employed last winter/spring (i.e., visual spotlighting surveys from the road at night). Do not use the distance method to estimate abundance or density. Rather, use simple counts of deer seen from the road as an index of deer abundance.

The perpendicular distance to individuals or herds can be recorded with GPS in order to map the location of deer. The map data will also be useful for defining the observable area. Further definition of the observable area can be accomplished with GIS using aerial photography, digital elevation maps, etc. By quantifying the area over which deer may generally be seen from the road, this will provide an index of density.

These measures would not be thought of as estimates of the actual deer abundance or density per se (as would be the case if one were using the distance method), but simple indices of these variables. These indices, however, would vary in direct proportion to the variables of interest, and would indicate whether deer populations were changing, and the general magnitude of the change. This would represent the minimum information deemed necessary by park managers for which deer were designated as vital signs.

- (2) Infrequently (every 3-5 years, depending upon budget or other considerations), mark-recapture or other methods could be employed to obtain more accurate estimates of deer abundance or density. This double sampling approach would allow us to determine correlations between the annual index of deer populations with the more accurate abundance data determined from other methods. Ultimately, it should be possible to estimate deer abundances with relatively good accuracy in years when only index data from visual surveys are available.

Supplement 3. Sample Size Analysis

Comparison of confidence interval widths as a function of number of survey nights

The following analysis and assessments were important in the development of version 2.0 of the protocol. They are provided here for historical context and as evidence for changes to the protocol over its lifetime.

As sample size (i.e., number of survey nights) increases, the amount of uncertainty surrounding the point estimate (i.e., confidence intervals) decreases.

Comparing the width of confidence intervals for sample sizes of 3, 4, 5, and 6 (# of survey nights), the greatest relative decrease occurs between sample sizes of 3 and 4. Based on this relationship and the increasing costs associated with more survey nights, the minimum number of survey nights was set at 4.

The data used to construct this graph were actual data collected at Wilson's Creek National Battlefield from 2008 to 2015.

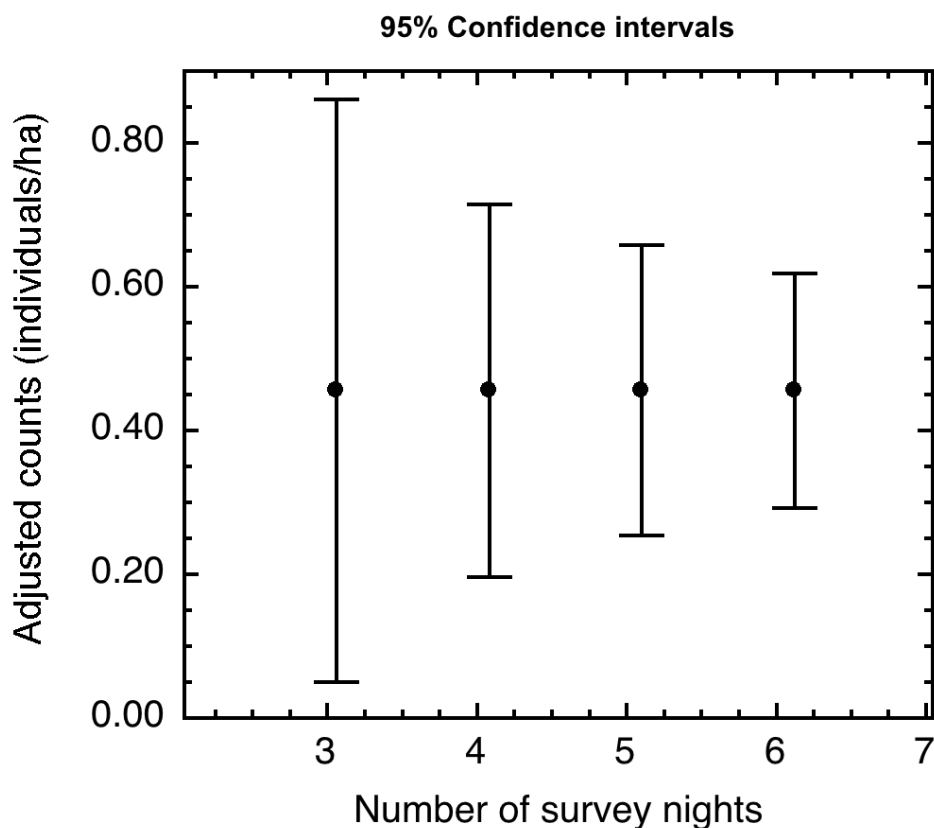


Figure S3-1. 95% confidence intervals for adjusted counts (individuals/ha) at sample sizes of 3, 4, 5, and 6 (# survey nights). Data collected at Wilson's Creek National Battlefield, 2008–2015.

Supplement 4. Evaluation of Nightly Replicates

Evaluation of the efficacy of three nightly replicates

The following analysis and assessments were important in the development of version 2.0 of the protocol. They are provided here for historical context and as evidence for changes to the protocol over its lifetime.

We evaluated the efficacy of three nightly replicates. The highest evening count is often the first replicate count. The second and third replicates combined, however, produced the highest evening count on one-third of sample days. As a result, the revised protocol retains three nightly replicates. The only exception is the third replicate count on the third sample day is replaced with an additional visible area estimate.

Table S4-1. The percent of sample days the first, second, and third replicate counts produce the nightly maximum number of deer, 2008–2016.

Park	Replicate		
	1	2	3
Arkansas Post National Memorial (n=46 replicates)	57%	24%	20%
Pea Ridge National Military Park (n=49 replicates)	73%	8%	18%
Wilson’s Creek National Battlefield (n=52 replicates)	69%	17%	13%

Supplement 5. Visible Area Estimate Analysis

Effect of adjusting the visible area estimate by the mapped location of deer recorded during all replicates (2008–2016)

The following analysis and assessments were important in the development of version 2.0 of the protocol. They are provided here for historical context and as evidence for changes to the protocol over its lifetime.

The 2007 protocol calls for a single visible area estimate. The visible area estimate is adjusted with

the mapped location of all deer during all replicates. That is, if deer were mapped outside the visible area, the visible area boundary was moved to include the observed deer. The GIS processing required to map all deer locations is significant (40–60 hr). We evaluated the effect of adjusting the visible area estimate with mapped deer locations and found, on average, the adjustment increased the visible area by 15% (Table S5-1). To reduce the required processing time, we will conduct two rounds of visibility estimates in lieu of adjusting a single visibility estimate with the mapped location of deer. Two visibility estimates will yield a finer scale estimate of visible area.

Table S5-1. Visible area estimate using one replicate assessment, and adjustments for deer observed outside the visible area.

Park	Year	Visible Area Estimate (ha)	Adjusted Visible Area Estimate (ha)	Percent Increase in Visible Area from Adjustments
ARPO	2008	98	120	22%
	2009	96	110	15%
	2010	84	97	15%
	2011	61	84	38%
	2012	91	103	13%
	2013	73	79	8%
	2014	79	86	9%
	2015	75	85	13%
	2016	108	116	7%
PERI	2008	246	303	23%
	2009	270	311	15%
	2010	255	268	5%
	2011	262	281	7%
	2012	259	281	8%
	2013	258	286	11%
	2014	246	267	9%
	2015	302	327	8%
	2016	285	301	6%
WICR	2008	195	242	24%
	2009	233	276	18%
	2010	168	188	12%
	2011	199	228	15%
	2012	263	324	23%
	2013	224	273	22%
	2014	164	197	20%
	2015	229	267	17%
	2016	191	217	14%
Overall Average:	–	–	–	15%

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Natural Resource Stewardship and Science

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