THE ABILITY OF AERIAL SURVEYS USING THERMAL INFRARED IMAGERY TO DETECT CHANGES IN ABUNDANCE OF WHITE-TAILED DEER ON PENNSYLVANIA STATE FORESTS

by

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Executive Summary

In winter 2005 the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry conducted 10 aerial surveys of portions of 8 state forests to count white-tailed deer using forward-looking infrared (FLIR) technology. Aerial counts of deer using FLIR technology have been conducted in Pennsylvania, but relatively little research has been conducted on the ability of these counts to provide accurate population estimates. The Pennsylvania Game Commission conducted a literature review of FLIR technology and concluded, as applied to white-tailed deer, the technique provided inconsistent results because of differences in methods and equipment. The most recent peer-reviewed research evaluating FLIR technology in a deciduous forest environment reported that nine aerial surveys missed 11–69% of the deer.

I used four repeated surveys of the Dents Run area in Elk State Forest to estimate the precision (repeatability) of FLIR aerial surveys for deer. I then used this estimate of precision to investigate the ability (statistical power) of FLIR aerial surveys to detect various declines in deer abundance.

The data used in the analysis were from flights conducted on 13 and 14 April 2005 when each of these nights two complete surveys of the study area were conducted. On 13 April, 63 and 73 deer were observed (10.0 and 11.6 deer/mi^2). On 14 April, 70 and 77 deer were observed (11.1 and 12.2 deer/mi^2). This resulted in a mean count of 70.75 deer (11.2 deer/mi^2), a standard deviation of 5.9090, and a coefficient of variation of 0.08352.

The power analysis indicated that three replicate surveys per year could detect a $\geq$20% decline in deer abundance with >80% probability. This is equivalent to detecting a decline from 10 deer/ mi^2 to 8 deer/ mi^2, or on a 50 square mile study area a decline from 500 deer to 400 deer. Two replicate surveys per year could detect a $\geq$50% decline in abundance, and six replicate surveys could detect a $\geq$10% decline. The number of replicate surveys required for making deer harvest management decisions would depend on the research or management objectives of a specific project. It is likely that most wildlife managers and administrators would prefer to be able to detect population declines of 20% with good confidence (>80% power).

This analysis did not address whether FLIR aerial surveys provide unbiased population estimates. Estimating bias requires knowledge of the true number of deer on the study area, which would be an expensive undertaking. By accepting the assumption that bias is constant among observers and years, FLIR aerial surveys could be used to monitor trends in deer abundance. However, research to date suggests bias may be a concern for FLIR surveys of deer in deciduous forests (e.g., Haroldson et al. 2003) and more research to directly address this issue is warranted. If bias is not constant, a greater number of replicate surveys would be required to detect the same population change.

These results demonstrate that variability in counts of deer from FLIR aerial surveys needs to be incorporated in statistical analyses to ensure correct inferences are made about changes in deer abundance. That is, a change in the number of deer observed from one year to the next based on single FLIR surveys simply could be caused by inherent variability in the number of deer counted using this technique, unless the decline was exceedingly large.

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Introduction

In winter 2005 the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry conducted 10 aerial surveys of portions of 8 state forests to count white-tailed deer (*Odocoileus virginianus*) using forward-looking infrared (FLIR) technology (http://www.dcnr.state.pa.us/forestry/deer/deersurvey.aspx). This technology uses infrared sensors to convert infrared radiation into the visible spectrum, which improves the ability to detect deer because deer are warmer than the surrounding environment and their cryptic coloration in the visible spectrum is irrelevant. Ideally, such surveys are conducted when environmental temperatures are much cooler than the temperature of deer and when the least amount of obstructing vegetation exists. Consequently, surveys often are conducted at night (e.g. Wiggers and Beckerman 1993, Haroldson et al. 2003) during the seasons of the year when deciduous trees have shed their leaves because thermal radiation does not penetrate green-leaf canopy (Graves et al. 1972, Wilde 2000, Potvin and Breton 2005).

Aerial counts of deer using FLIR technology have been conducted in Pennsylvania (e.g., Bernatas 2004*a*, 2004*b*), but relatively little research has been conducted on the ability of these counts to provide accurate population estimates. The Pennsylvania Game Commission conducted a literature review of FLIR technology and concluded, as applied to white-tailed deer, the technique provided inconsistent results because of differences in methods and equipment (Mumma 2005). The most recent peer-reviewed research evaluating FLIR technology in a deciduous forest environment (Harsoldson et al. 2003) reported that FLIR technology provided biased and variable population estimates. Haroldson et al. (2003) estimated that nine aerial surveys using FLIR technology missed 11–69% of the deer and, on average, detected 56% of deer on the study area. Haroldson et al. (2003:1188) concluded, "Until the capabilities of thermal imaging are more fully understood and the sampling protocols refined, detection rates may be too variable to provide reliable counts of animal abundance."

A technique that provides reliable population estimates must have minimal bias and be precise. Bias is the difference between the estimated population size and the true population size. A precise population estimator provides similar population estimates over repeated surveys. [Note: A population estimator is simply a mathematical expression that indicates how to calculate an estimate of the true population size. In the context of FLIR surveys the estimator is simply the count of number of deer observed.] The ideas of bias and precision are best illustrated using the analogy of target shooting with a rifle. In Figure 1 an ideal population estimation technique would be like the target in the lower left-hand corner – repeated surveys would provide similar estimates in which the mean of these repeated surveys would be close to the true population size (the bulls-eye).

Evaluating whether a population estimation technique provides unbiased estimates is oftentimes difficult, especially for deer, because one needs to know the true population size. Consequently, usually it is unknown if a given population estimate is truly accurate. Some estimators still can be useful, however, even though they may have some combination of bias and imprecision. For example, consider the target in the upper left-hand corner that has a very

tight group of shots (precise) but they are biased (missed the bulls-eye, or true population estimate). Such a biased, but precise, estimator potentially still could be useful because even though the estimates may not accurately represent the true population size, they could detect small relative changes in the population over time. However, this bias would have to be constant over time.

Precise but biased   Imprecise and biased

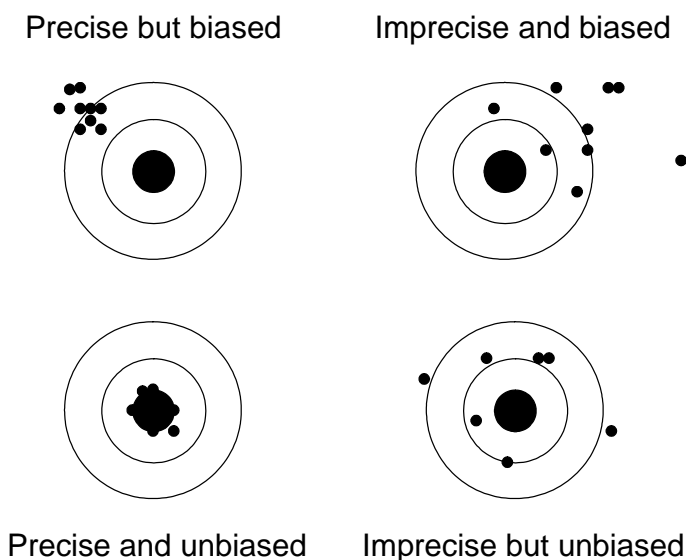Precise and unbiased   Imprecise but unbiased

Figure 1. Illustration of bias and precision of population estimates using a target shooting analogy (from White et al. 1982).

Evaluating the precision, or repeatability, of a population estimator can be accomplished even if the true population size is unknown. This assessment is done by conducting repeated surveys during a period in which the population is not expected to change, but assuming bias is constant. By obtaining a measure of the precision of the estimator it is possible to estimate the ability of an estimator to detect a given population change, which is called statistical power. For example, if we surveyed an area twice one year and the same area twice the following year, we could use statistics to test whether the population had changed and calculate an estimate of the probability that the population size in the second year was in fact different. Similarly, given the variability in our population estimates, the expected change in population size, and the number of replicate surveys, we could estimate the probability (statistical power) that we could detect a given change in population size.

It is this evaluation of the statistical power of FLIR aerial surveys to detect changes in deer abundance that is the focus of this report. I used repeated counts of deer from FLIR aerial surveys conducted on the Dents Run portion of the Elk State Forest to estimate the precision of this survey technique. In turn, I used this estimate of precision to investigate the statistical power of FLIR aerial surveys to detect declines in deer abundance.

Study Area

The study area was located in Elk State Forest in an area called Dents Run (Figure 2). This area is 4,028 acres (6.29 sq. miles) and located in Elk County and Wildlife Management Unit 2G. Also, this area was enrolled in the Pennsylvania Game Commission's Deer Management Assistance Program (Area #54) for the 2003-04 and 2004-05 hunting seasons, and will be enrolled for the 2005-06 hunting season.

The habitat on this study area is typical of northcentral Pennsylvania. The study area is located in the Allegheny Plateau Region, which ranges in elevation from 275–701 m and annually receives 91–102 cm of moisture. The study area is primarily forested and located within the transition zone between the mixed oak (*Quercus* spp.) and hickory (*Carya* spp.) forest to the south and the northern hardwood forest (beech [*Fagus grandifolia*], cherry [*Prunus* spp.], birch [*Betula* spp.], and maple [*Acer* spp.]) to the north. The topography is steep but with relatively good road access. The boundary of the study area follows drainages and roads, and the center of the study area contains a series of forest openings maintained as wildlife food plots. The center of the study area is accessible by gated Bureau of Forestry roads.
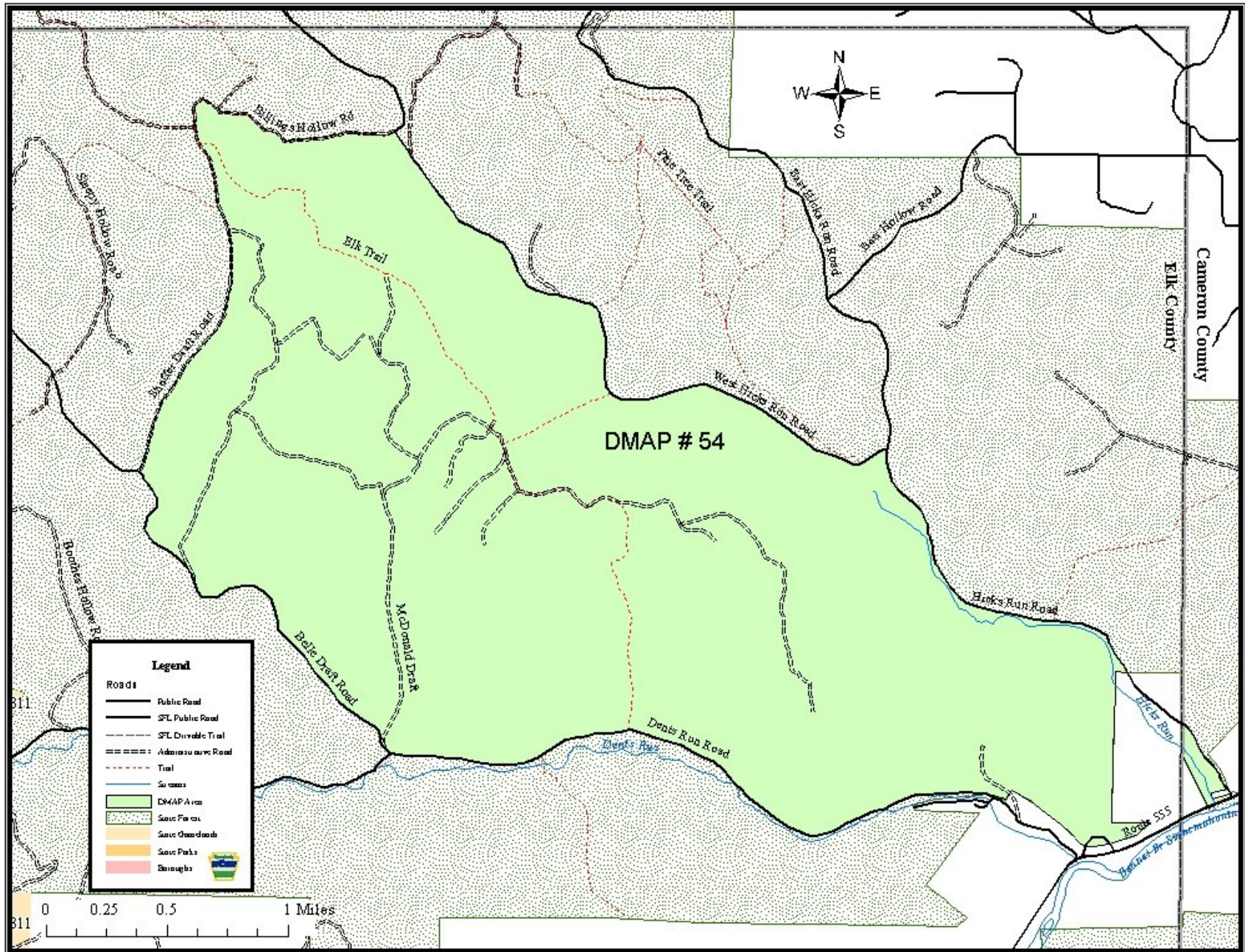
Figure 2. Map of Dents Run study area in the portion of the Elk State Forest, Elk County, Pennsylvania (obtained from http://www.dcnr.state.pa.us/forestry/dmap/maps/d13_54.jpg).

Methods

Aerial surveys using FLIR technology were conducted in April 2005 by Vision Air Research, Inc. (Boise, Idaho). Although the final report from Vision Air Research had not been submitted by the time of writing of this report, the methods used to conduct the survey were likely similar to other surveys conducted in Pennsylvania (Bernatas 2004*a*, 2004*b*). Other surveys in Pennsylvania were conducted after sunset in which transects 1,000 feet apart were flown across the study area at flight speeds of approximately 80 nautical miles per hour. The pilot navigated transects using a global positioning system (GPS) and the observer used the infrared sensor mounted on a gimble system to search for deer. All imagery from the FLIR sensor along the transect was videotaped, which were later reviewed to count deer and map their locations.

The FLIR surveys provided total counts of deer on each flight. I used these counts to calculate an estimate of the mean number of deer counted

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \, ,$$

where x_i is the number of deer observed on flight i and n is the number of replicate flights conducted. I then estimated the standard deviation (SD) of these counts, which is a measure of the precision of the estimator $\bar{x}$,

$$SD = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \, .$$

I then calculated the coefficient of variation (CV) as

$$CV = \frac{SD}{\bar{x}} \, .$$

To estimate the statistical power of FLIR surveys to detect specified declines in deer abundance I assumed that the random variable x_i (counts of deer from the FLIR surveys) followed a *t* distribution. Typically, statistical power is estimated analytically by assuming the variances of the two estimates are the same (e.g., Williams et al. 2002). However, counts of wildlife populations typically exhibit a correlation between the parameter of interest (e.g., abundance) and the SD. Consequently, I wrote a program in SAS (SAS Institute, Cary, North Carolina) to relax this assumption and assumed the SD and mean were related linearly (i.e., the CV was constant). This relationship is illustrated in Figure 3, in which as population size increases the CV remains constant but the SD increases linearly. Figure 4 provides the SAS code used to generate estimates of statistical power.
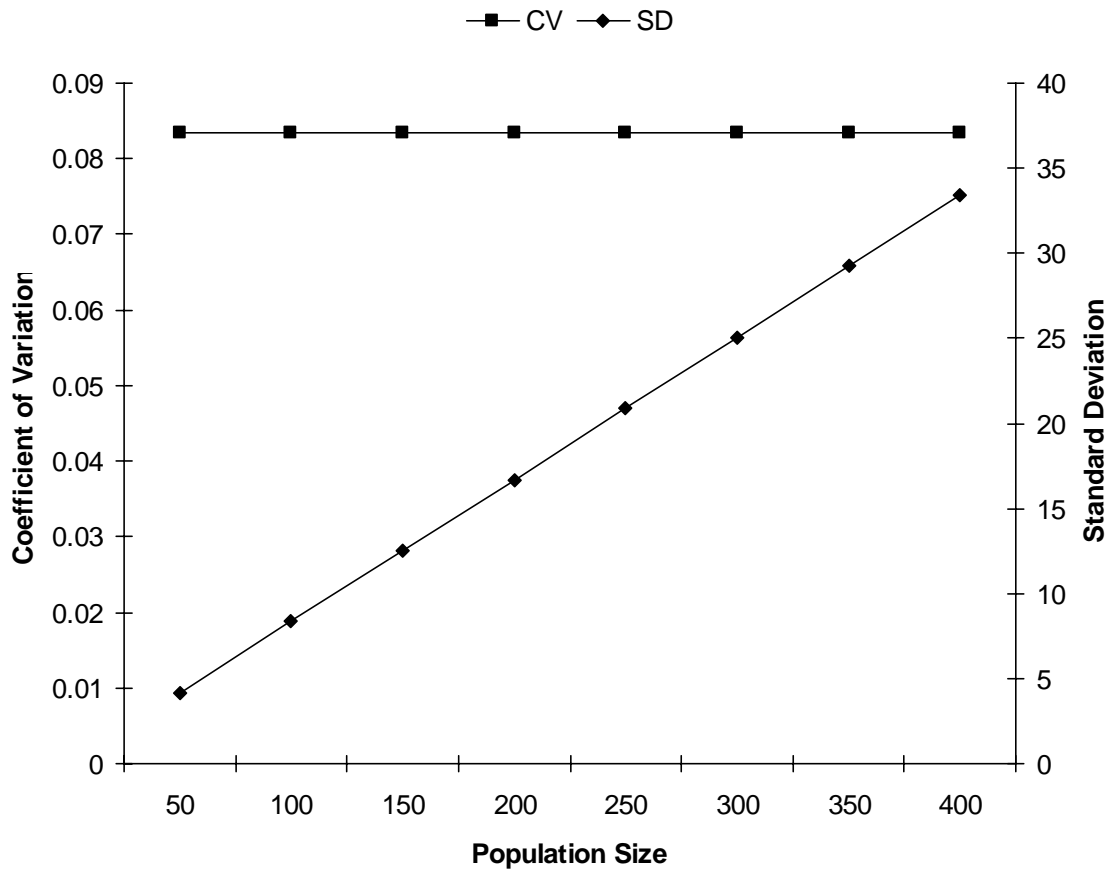
Figure 3. Relationship between population size, standard deviation, and coefficient of variation used in the analysis to estimate statistical power of FLIR surveys to detect declines in abundance of white-tailed deer.

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*************************************************
*
*      This program estimates statistical power to
*       detect changes in counts of deer from FLIR
*        surveys.
*
*
*      Written by Duane R. Diefenbach, July 2005
*************************************************;

data one;
 cv=.08352; N1=400;
 do reps = 2 to 10;              * Number of replicate surveys;
     do diff=0 to 90 by 10;   * Decline in Pop Size on a percentage scale;
        N2=N1-diff/100*N1;       * Population size at time 2;
      se1=cv*N1/sqrt(reps);      * Std Err at time=1;
        se2=cv*N2/sqrt(reps);    * Std Err at time=2;

 Ncrit=N1+tinv(.05,reps-1)*se1; *Population size in which alpha=.05 under N1;
 Power=probt((Ncrit-N2)/se2,reps-1);*Probability of 1-Type II error under N2;

 output;
 end; end;

proc print label;
 label N1='Population Time 1' N2='Population Time 2'
        diff='Percent Population Decline'
      reps='No. Replicate Surveys' se1='SE(N1)' se2='SE(N2)'
      Ncrit='Critical Value (alpha=.05)' Power='Statistical Power';
 title 'Power to Detect Declines in Population Size using FLIR Surveys';
 var N1 N2 diff reps se1 se2 Ncrit power;
proc plot;
 plot power*reps=diff;
 quit;
run;
```

Figure 4. SAS program written to estimate statistical power of FLIR aerial surveys to detect declines in white-tailed deer abundance for differing percent declines in population size and number of replicate surveys conducted per year.

Results

Six flights were conducted during April 2005, but two flights did not encompass the complete study area. Consequently, data from the two incomplete flights were excluded from the statistical analysis. Figures 6-8 are maps of the locations of deer during each flight.

The data used in the analysis were from flights conducted on 13 and 14 April 2005 when each of these nights two complete surveys of the study area were conducted. On 13 April, 63 and 73 deer were observed (10.0 and 11.6 deer/mi^2). On 14 April, 70 and 77 deer were observed (11.1 and 12.2 deer/mi^2). This resulted in a mean count of 70.75 deer (11.2 deer/mi^2), a SD of 5.9090, and a CV of 0.08352.

The power analysis indicated that three replicate surveys per year could detect a $\geq$20% decline in deer abundance with >80% probability (Figure 5). This is equivalent to detecting a decline from 10 deer/ mi^2 to 8 deer/ mi^2, or on a 50 square mile study area a decline from 500 deer to 400 deer. Two replicate surveys per year could detect a $\geq$50% decline in abundance, and 6 replicate surveys could detect a $\geq$10% decline (Figure 5).
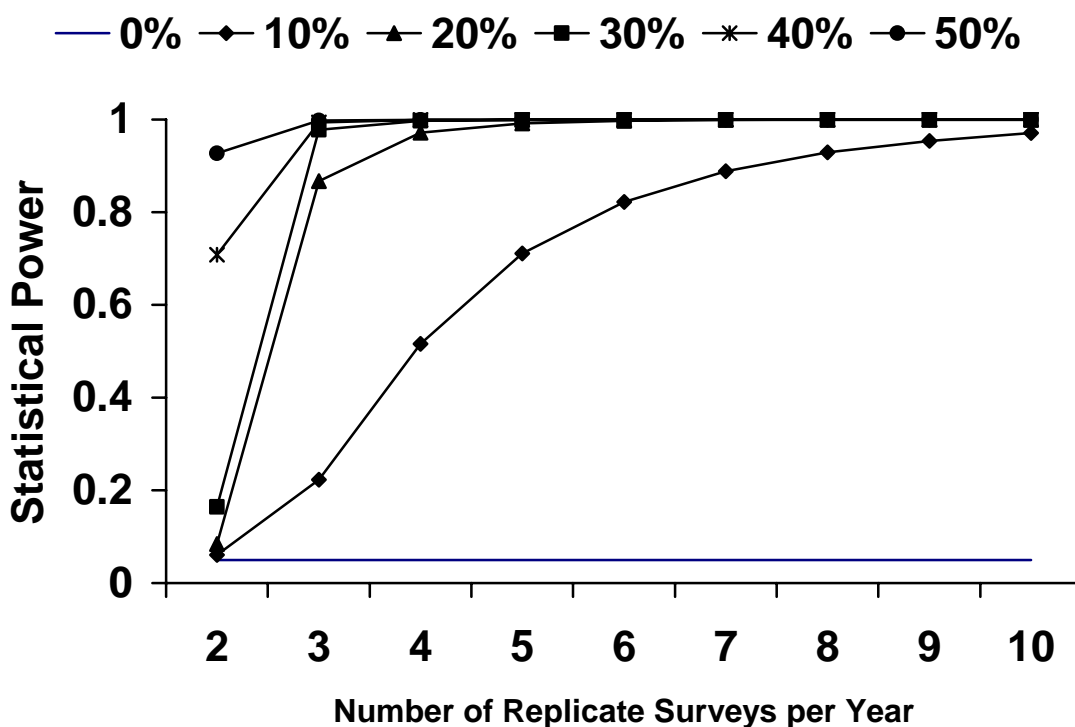

Figure 5. Probability (statistical power) of detecting 0–50% declines in abundance using 2–10 replicate FLIR aerial surveys per year. Two replicate surveys per year had a >99% probability of detecting >50% declines in abundance.

Figure 6. Number and location of white-tailed deer observed during a forward-looking infrared aerial survey of the Dents Run portion of Elk State Forest, Elk County, Pennsylvania, 13 April 2005.
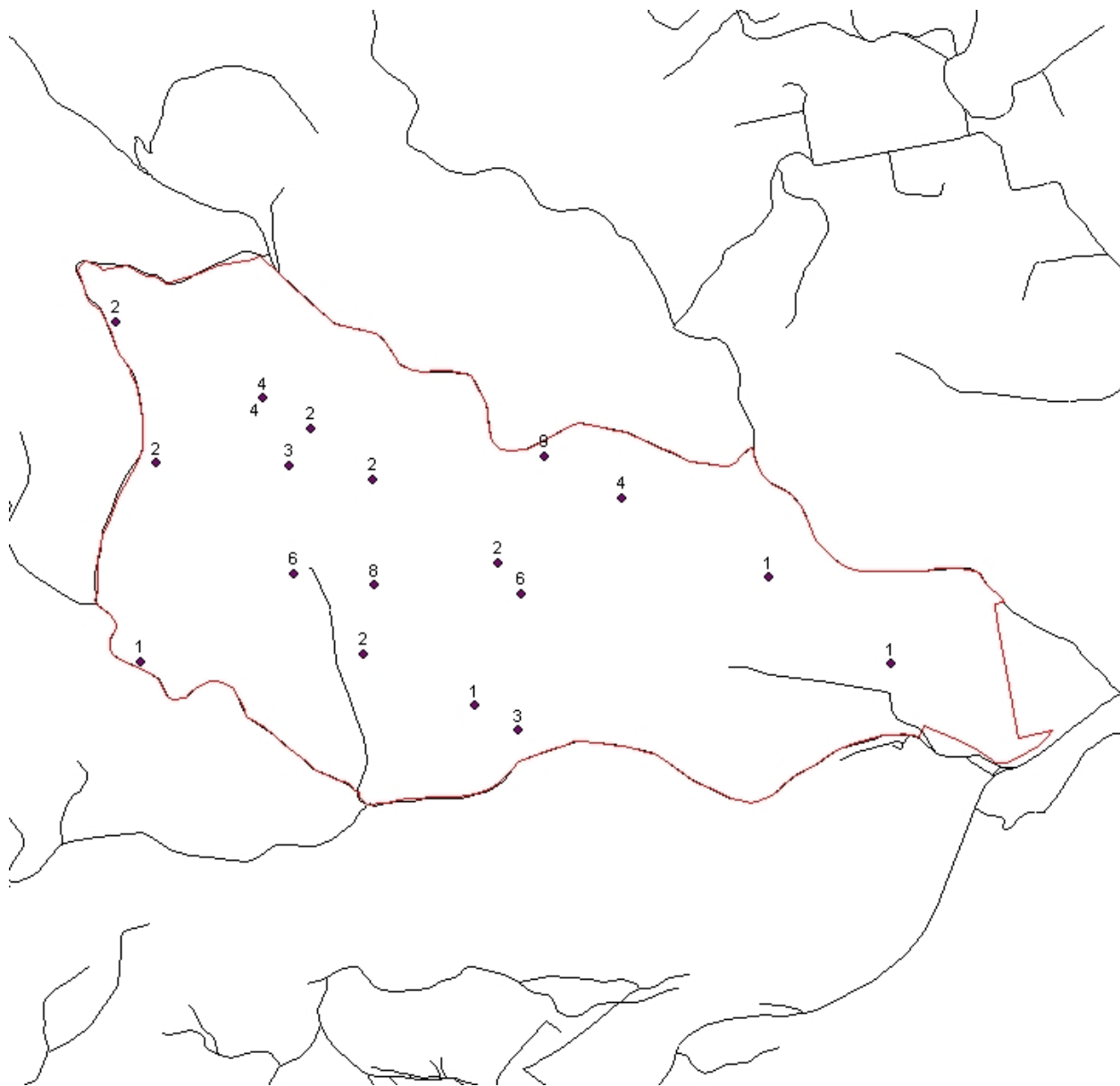
Figure 7. Number and location of white-tailed deer observed during a forward-looking infrared aerial survey of the Dents Run portion of Elk State Forest, Elk County, Pennsylvania, 13 April 2005.

Figure 8. Number and location of white-tailed deer observed during a forward-looking infrared aerial survey of the Dents Run portion of Elk State Forest, Elk County, Pennsylvania, 13 April 2005. These data were not analyzed because the survey was incomplete.
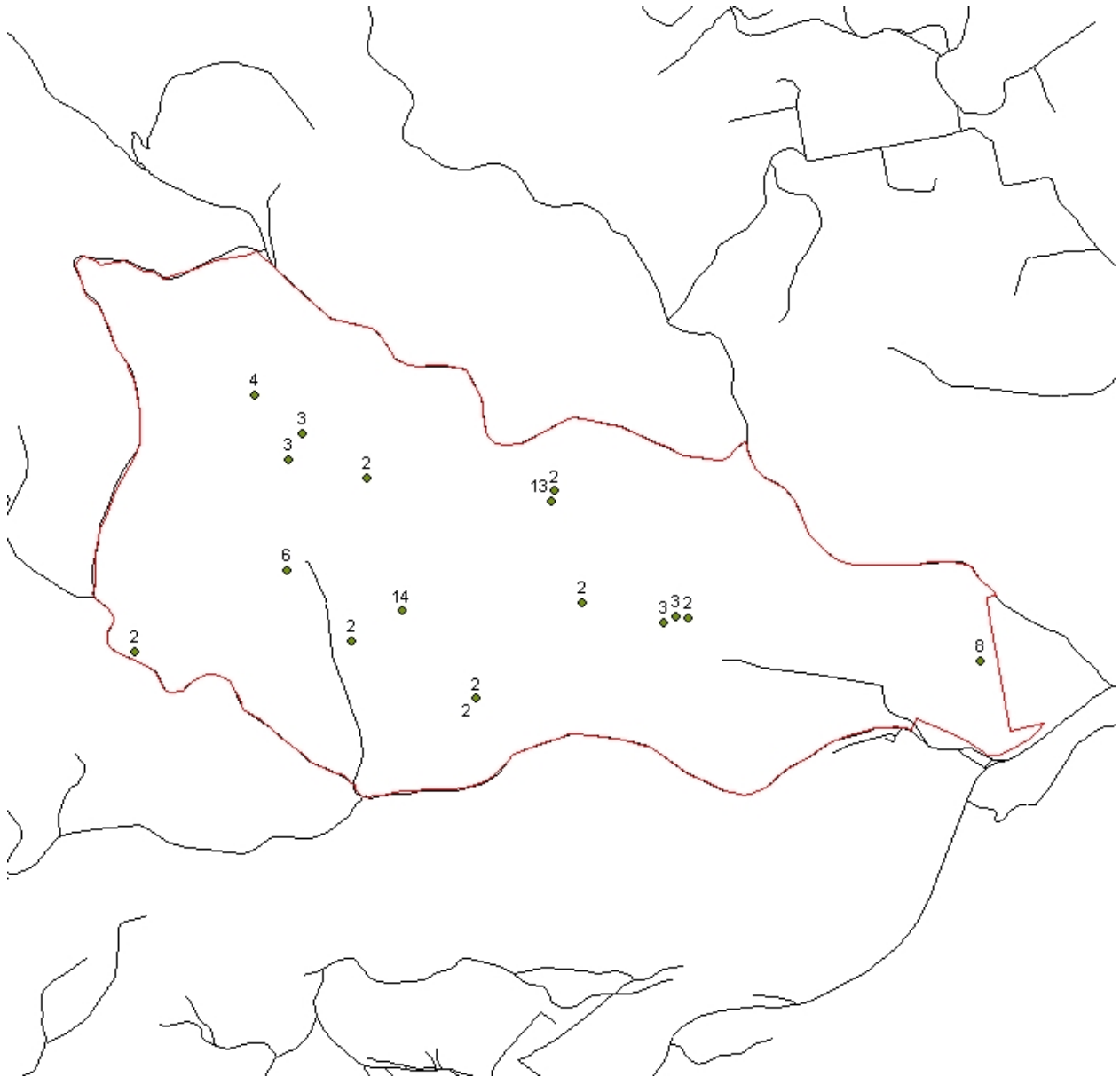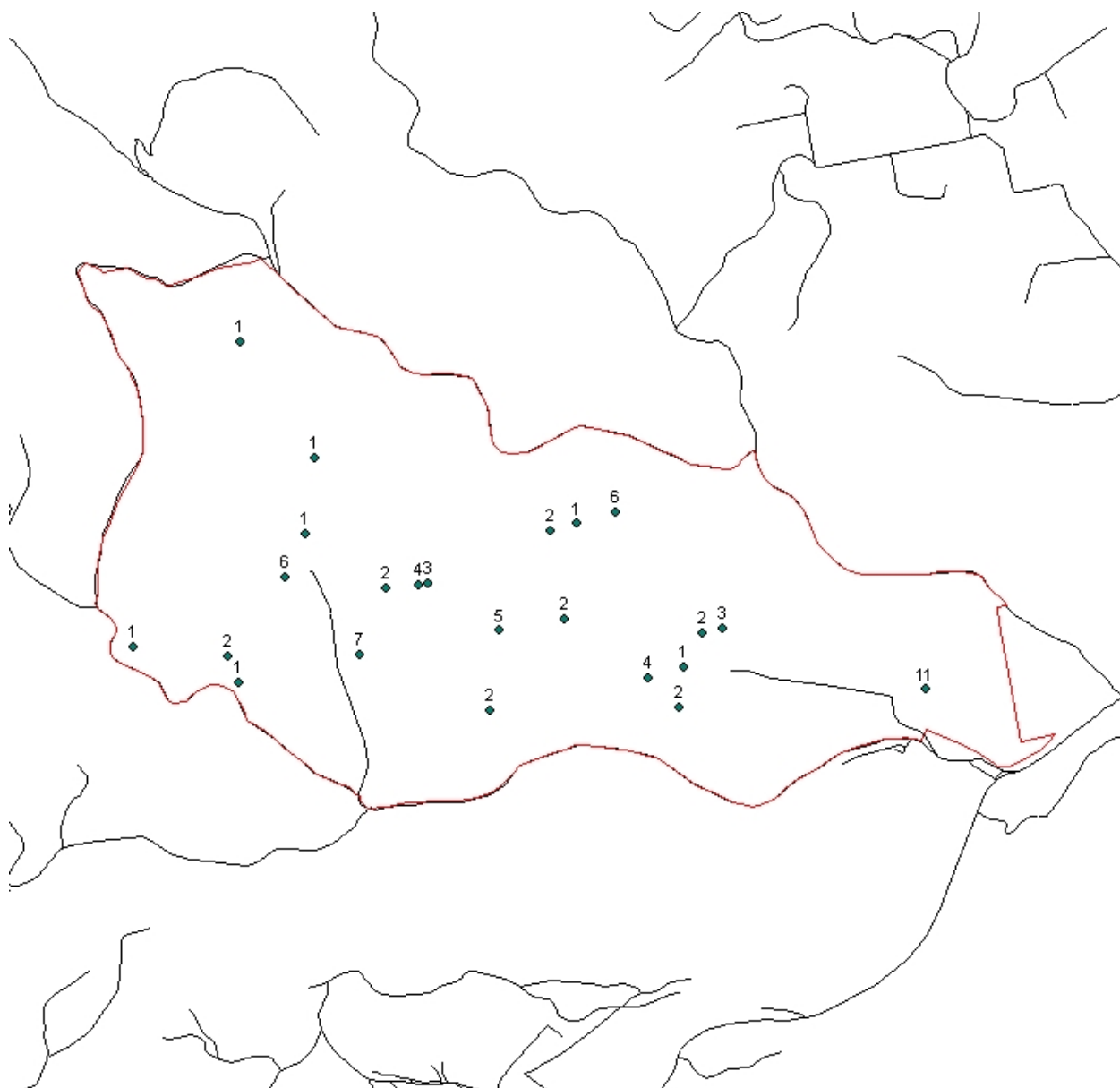
Figure 9. Number and location of white-tailed deer observed during a forward-looking infrared aerial survey of the Dents Run portion of Elk State Forest, Elk County, Pennsylvania, 14 April 2005.

Figure 10. Number and location of white-tailed deer observed during a forward-looking infrared aerial survey of the Dents Run portion of Elk State Forest, Elk County, Pennsylvania, 14 April 2005.
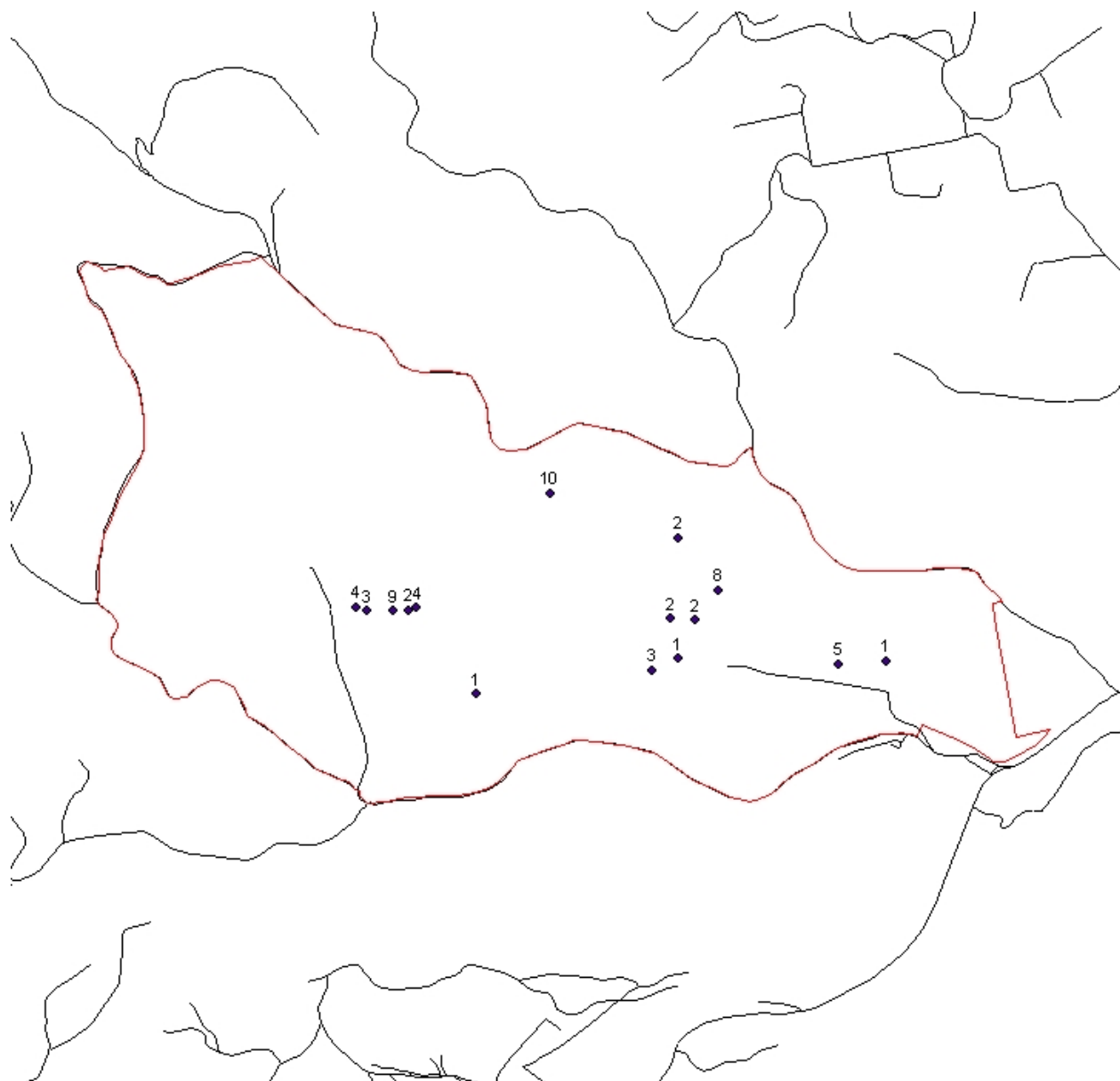
Figure 11. Number and location of white-tailed deer observed during a forward-looking infrared aerial survey of the Dents Run portion of Elk State Forest, Elk County, Pennsylvania, 14 April 2005. These data were not analyzed because the survey was incomplete.
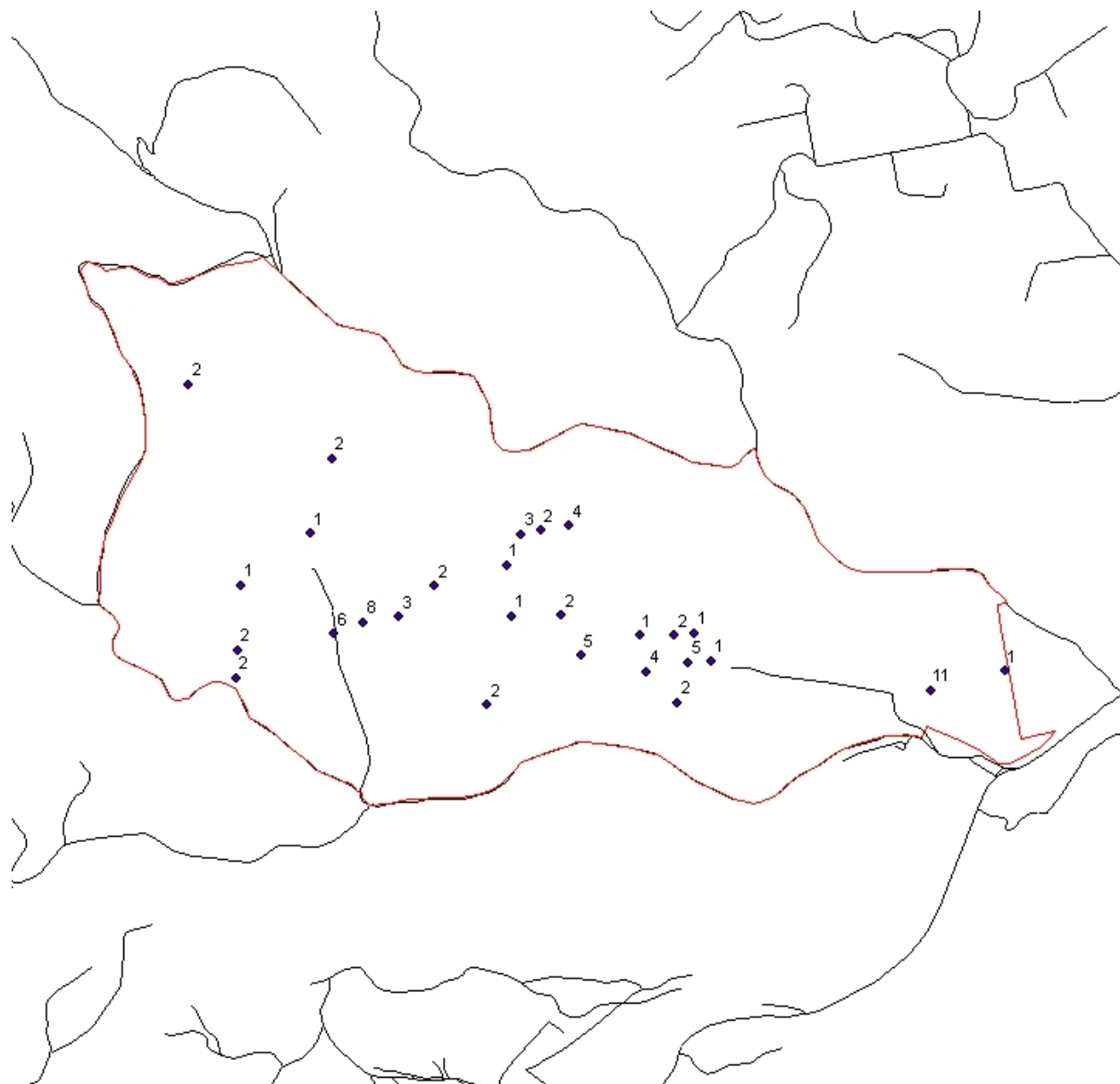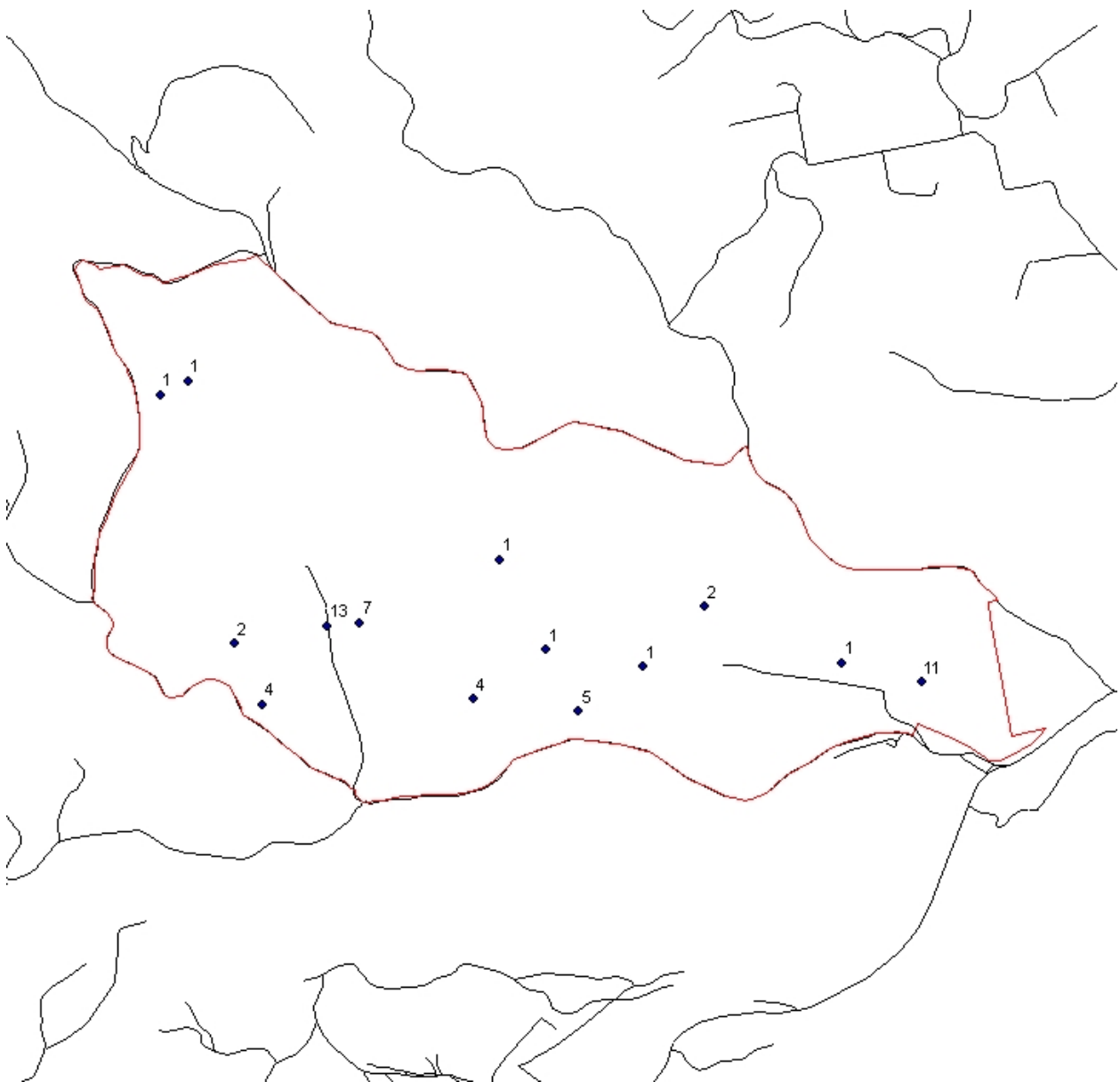
Discussion

Conducting repeated FLIR aerial surveys on the same study area provided an opportunity to evaluate the precision of this technique for monitoring deer populations. The results of this study demonstrate that variability in counts needs to be incorporated in statistical analyses to ensure correct inferences are made about changes in a population. That is, a change in the number of deer observed from one year to the next based on single FLIR surveys simply could be caused by inherent variability in the number of deer counted using this technique, unless the decline was exceedingly large.

My analyses indicated that at least two replicate surveys per year must be conducted to detect large (>50%) declines in deer abundance and three replicate surveys would have a good chance (>80%) of detecting a ≥20% decline. However, whether two replicate surveys would be acceptable for making deer harvest management decisions would depend on research or management objectives of a specific project. It is likely that most wildlife managers and administrators would prefer to be able to detect population declines of 20% with good confidence (>80% power).

The variability observed with these repeated flights could be caused by two factors: (1) deer movements on and off the study between survey flights, and (2) deer being missed by the observer. I suspect that both of these factors may be occurring because 3–16 deer were located <200 m from the edge of the study area over the four surveys and none of the thermal infrared studies on white-tailed deer reviewed by Mumma (2005) reported a detection rate >89%. Regardless of the cause of the variability in counts, this study demonstrates that this variability needs to be incorporated into the sampling design of any program using thermal infrared imagery technology to monitor changes in abundance of deer. The movements of deer on and off a study area would be more problematic on smaller survey areas.

This analysis did not address whether FLIR aerial surveys provide unbiased population estimates. Estimating bias requires knowledge of the true number of deer on the study area, which likely would be an expensive undertaking. By accepting the assumption that bias is constant among observers and years, FLIR aerial surveys could be used to monitor trends in deer abundance. However, research to date suggests bias may be a concern for thermal infrared surveys of deer in deciduous forests (e.g., Haroldson et al. 2003) and more research to directly address this issue is warranted. If bias is not constant, a greater number of replicate surveys would be required to detect the same population change.

The results of this research also have implications if a sampling approach is used to make inferences about deer abundance. That is, rather than surveying the complete area and trying to count every deer, a random sample of areas are surveyed, and a survey design (e.g. Cochran 1977) is used to estimate the total number of deer on the study area or management unit. Such an approach could be more cost-effective, but would require additional investigation into the precision of resulting population estimates and the power to detect specific changes in deer abundance.

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