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Research Article

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Abstract

*Wildlife managers require reliable, cost-effective, and accurate methods for conducting population surveys in making wildlife management decisions. Traditional methods such as spotlight counts, drive counts, strip counts (aerial, thermal, infrared) and mark–recapture techniques can be expensive, labor-intensive, or limited to habitats with high visibility. Convenience sampling designs are often used to circumvent these problems, creating the potential for unknown bias in survey results. Infrared-triggered cameras (ITCs) are a rapidly developing technology that may provide a viable alternative to wildlife managers because they can be economically used with alternative sampling designs. We evaluated population-density estimates from unbaited ITCs and road surveys for the endangered Florida Key deer (*Odocoileus virginianus clavium*) on No Name Key, Florida, USA (461-ha island). Road surveys (*$n = 253$*) were conducted along a standardized 4-km route each week at sunrise (*$n = 90$*), sunset (*$n = 93$*), and nighttime (*$n = 70$*) between January 1998 and December 2000 (total deer observed = 4,078). During this same period, 11 ITC stations (1 camera/42 ha) collected 8,625 exposures, of which 5,511 registered deer (64% of photographs). Study results found a difference (*$P < 0.001$*) between methods with road-survey population estimates lower (76 deer) than ITC estimates (166 deer). In comparing the proportion of marked deer between the 2 methods, we observed a higher (*$P < 0.001$*) proportion from road surveys (0.266) than from ITC estimates (0.146). Spatial analysis of deer observations also revealed the sample area coverage to be incongruent between the 2 methods; approximately 79% of all deer observations were on urban roads comprising 63% of the survey route. Lower road-survey estimates are attributed to 1) urban deer behavior resulting in a high proportion of marked deer observations, and 2) inadequate sample area coverage. We suggest that ITC estimates may provide an alternative to road surveys for estimating white-tailed deer densities, and may alleviate sample bias generated by convenience sampling, particularly on small, outer islands where habitat and/or lack of infrastructure (i.e., roads) precludes the use of other methods.*
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Key words

Florida Key deer, infrared-triggered cameras, Odocoileus virginianus clavium*, population density, road surveys, white-tailed deer.*

Reliable population estimates are paramount in the field of wildlife ecology (Jenkins and Marchinton 1969) because assessment of the stock on hand is a prerequisite for many wildlife management endeavors (Leopold 1933). Population-density estimates are important for implementing harvest strategies or in developing proper conservation policy and management protocols (Gelatt and Siniff 1999, Koenen et al. 2002, Swann et al. 2002). Since white-tailed deer (*O. virginianus*) are the most economically important big-game mammal in North America (Beechinor 1986, Schaefer and Main 2001), obtaining reliable population estimates is both a necessary and worthwhile component of white-tailed deer management. Reliable population estimates are even more important with threatened or endangered species, such as the Florida Key deer whose recovery efforts require annual population monitoring (U.S. Fish and Wildlife Service [USFWS] 1999).

Traditional methodologies such as drive counts, strip counts (aerial, thermal, infrared), and mark–recapture techniques can be expensive, labor-intensive, or limited to habitats with high visibility (Lancia et al. 1994, Jacobson et al. 1997). As a result, sampling designs often are altered to obtain estimates in a nonrandom fashion, which lowers the cost and/or effort required to obtain the estimate. Convenience sampling of this sort has been criticized widely within literature due to the probability of bias that is inherent to this type of sample design (Anderson 2001, Mackenzie and Kendall 2002, Thompson 2002, Anderson 2003, Ellingson and Lukacs 2003). Of greater concern is the lack of evidence to either validate the assumption that the sample is not biased by convenience sampling or to determine the amount and/or direction of bias resulting from the nonrandom sampling design.

Infrared-triggered cameras (ITCs) are a rapidly developing technology that may provide a viable alternative to wildlife managers as they can be economically used within a random or systematic sampling design. Due to their relatively small size, automated function, and robust sampling duration, ITCs can be used to conduct population surveys (Mace et al. 1994, Jacobson et al. 1997) and to study animal behavior and movements (Savidge and Seibert 1988, Carthew and Slater 1991, Mason et al. 1993, Foster and Humphrey 1995, Karanth 1995, Karanth and Nichols 1998). While previous research (Kucera et al. 1995, Jacobson et al. 1997, Koerth and Kroll 2000) suggest that ITCs are a useful means for estimating population densities, these studies were conducted using baited camera sites, which may introduce unwanted bias in the estimates. A basic assumption of mark–resight methods is that all animals have equal catchability (Krebs

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1999), which may not be the case when using bait to draw animals into the sample area. Information on the utility of estimating white-tailed deer numbers with uniformly placed, unbaited ITCs is needed. Furthermore, mark–resight estimates from traditional road surveys and ITCs should be evaluated, including similarities in animal sightability between methods (i.e., equal catchability).

We compared estimates from traditional road surveys and ITCs for a marked island population of white-tailed deer. Florida Key deer are an endangered subspecies of white-tailed deer endemic to the Lower Florida Keys (Hardin et al. 1984). The Key deer population on No Name Key (461 ha) provided us with a unique opportunity to 1) compare estimates from unbaited ITCs to road surveys and 2) to evaluate the proportion of marked deer between the 2 methods. Comparable results would provide a precedent for using ITCs to estimate deer densities on the outer islands where a lack of roads precludes the use of traditional road surveys.

Study Area

The Florida Keys are a chain of small islands that extend southwest from peninsular Florida approximately 200 km. No Name Key (461 ha) is located in Monroe County, Florida, and is part of the National Key Deer Refuge (NKDR). Soils vary from marl deposits to bare rock of the oolitic limestone formation (Dickson 1955, Lopez et al. 2004*b*). Vegetation near sea level and in tidal areas is comprised of black (*Avicennia germinans*), red (*Rhisophora mangle*), and white mangroves (*Laguncularia racemosa*), and buttonwood (*Conocarpus erecta*). With increasing elevation, maritime zones transition into hardwood (e.g., gumbo limbo [*Bursera simaruba*], Jamaican dogwood [*Piscidia piscipulaa*]) and pineland (e.g., slash pine [*Pinus elliottii*], saw palmetto [*Serenoa repens*]) upland forests with vegetation intolerant of salt water (Dickson 1955, Folk 1991, Lopez et al. 2004*b*).

Methods

Deer were captured and marked on No Name Key between January 1999 and December 2000 using portable drive nets (Silvy et al. 1975), drop nets (Lopez et al. 1998), and hand capture (Silvy 1975, Lopez 2001). Deer were physically restrained after capture with an average holding time of 10–15 minutes (no drugs were used). Sex, age, capture location, body weight, radio frequency (if applicable), and body condition were recorded for each deer prior to release (Lopez et al. 2003*b*). Captured deer were marked with plastic neck collars (8-cm wide) for adult and yearling females, leather antler collars (0.25-cm wide) for yearling and adult males, and elastic expandable neck collars (3-cm wide) for fawns (Lopez et al. 2004*a*). Neck collars were equipped with plastic ear tags for easy identification at a distance; 67–75% of the marked deer were equipped with radiotransmitters (Lopez et al. 2004*a*). Captured deer also were given an ear tattoo that served as a permanent marker (Silvy 1975).

Weekly road counts were conducted along a standardized 4-km route on No Name Key at sunrise, sunset, and nighttime from January 1999 to December 2000 (Fig. 1; Lopez et al. 2004*a*). Start and finish points were the same for each survey route. Sunrise surveys started 30 minutes before sunrise. Sunset surveys started 1.5 hours before sunset, and night surveys were conducted about 1 hour after sunset. Two observers in a vehicle traveled along the survey route (average travel speed 16–24 km/hr) and recorded the observed number (marked/unmarked), location, sex, and age (fawn, yearling, adult) on a map of the survey route (Lopez et al. 2004*a*). Deer were not counted on the backtrack portions of the road to alleviate the problem of double counting. Survey data were entered into an Access database and Arcview GIS for further analysis (Lopez 2001).

Eleven TrailMaster 1500 Active Infrared Trail Monitors (TrailMaster, Goodson and Associates, Lenexa, Kansas) consisting of a transmitter, receiver, and a 35-mm camera were uniformly placed throughout the study area (Fig. 1). First, we restricted camera placement to upland Key deer habitats (Lopez et al. 2004*b*), avoiding mangrove and buttonwood areas that are influenced by tides and not used by deer. We then divided inhabited areas into approximately 42-ha blocks (slightly higher camera density suggested by Jacobson et al. 1997); each block was then searched until a suitable (e.g., well-used deer trail, waterhole) camera location was found. Camera stations collected data from January 1999 to December 2000. Cameras were set to take pictures throughout the day (0001–2400 hr) with a delay between pictures of 30 minutes. The number of marked and unmarked animals including the animal's ear-tag number, sex, age, and location were recorded and entered into an Access database.

We determined weekly population estimates using a Lincoln-Petersen estimator for road surveys (Chapman's adjustment, sampling without replacement) and ITC data (Bailey's adjustment, sampling with replacement; Seber 1982). Population data

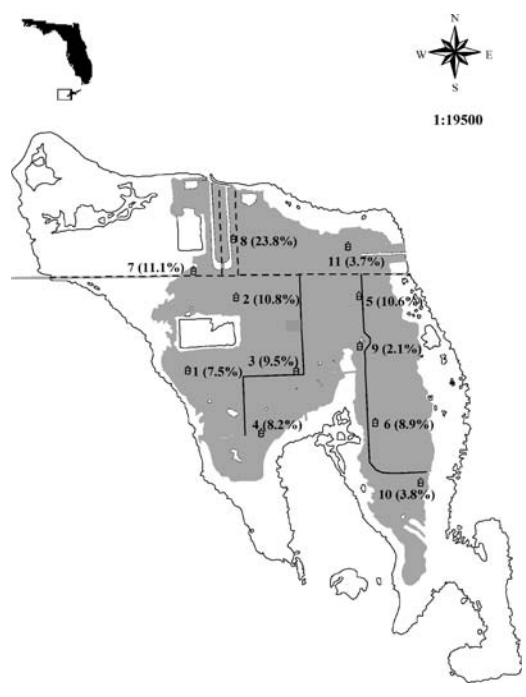

Figure 1. Road-survey route (4-km) and 11 infrared-triggered camera (ITC) stations used to estimate Key deer densities on No Name Key (461-ha), Monroe County, Florida, USA, Jan 1999–Dec 2000. Road survey is divided into urban (dashed line, 2.5-km) and rural roads (solid line, 1.5-km). Approximately 79% of total deer observations (3,222) were observed on urban roads compared to 21% for rural roads. The percent of Key deer observations (5,511) by camera station are in parentheses, the star symbol indicates approximate camera station placement. Gray shading represents areas inhabited by deer (upland areas).

(road surveys and photographs) met the requirements for this estimate because 1) the population was closed (i.e., study area is an island, with limited dispersal between islands and small population growth, Lopez et al. 2004*a*), and 2) a segment of the population was marked for individual identification during the study. The marked population (approx 67–75% of marked population included radiotransmitter) allowed us to readjust the number of available marked deer each week from telemetry data or survey data observations. Deer observations from ITC stations were pooled to determine a weekly population estimate.

Weekly estimates were randomly selected from both methods to generate a balanced design (a greater number of surveys were conducted in the fall to obtain reproductive data), which maximized the number of surveys within each season × method × year treatment combination. We applied the Lilliefors significance modification to the Kolmogorov-Smirnov test to determine whether the data were normally distributed. Levene's test for equal variance among treatment groups, followed by a spread versus level diagnostic regression (modified Box-Cox algorithm; SPSS 2001), was used to determine whether a variance-stabilizing transformation would be needed. Results indicated that a log (Y + 1) transformation was required to meet assumptions of a parametric ANOVA.

We tested for differences in population estimates between methods (road, ITC), seasons (spring, summer, fall, winter), and years (1999, 2000) using a 1) within-subjects factor, 2) between-subjects factor, split-plot (repeated measures) ANOVA (SPSS 2001). Seasons were defined as winter (Jan–Mar; pre-fawning season), spring (Apr–Jun; fawning season), summer (Jul–Sep; prebreeding season), and fall (Oct–Dec; breeding season; Lopez et al. 2004*a*). Repeated-measures ANOVA designs account for lack of independence when repeated observations are obtained from the same experimental units (Tzilkowski and Storm 1993, Zar 1996, Lomax 2001, von Ende 2001). Because only 2 levels existed for the within-subjects factor (year), compound symmetry was assured (i.e., only 1 covariance). As such, adjusted *F*-test (Geisser and Greenhouse 1958, Huynh and Feldt 1976) and MANOVA techniques (no compound symmetry assumption) were not required for the evaluation of these data. Results for each method were plotted separately for each year using the estimated marginal means for all 4 seasonal categories (SPSS 2001). For each weekly estimate, we compared the proportion of marked deer (number marked/total deer observed) between methods using an independent Student's *t*-test (SPSS 2001). All statistical comparisons were conducted at $\alpha = 0.05$.

Results

Road and ITC surveys were conducted from January 1999 to December 2000, except September 1999, due to the landing of Hurricane Irene (Lopez et al. 2003*a*). A weekly average of 22 deer (with a range between 18 and 35) were maintained in our marked herd. A total of 253 road surveys were conducted (sunrise $n = 90$, sunset $n = 93$, nighttime $n = 70$) with 4,078 deer observations (male = 1,411; female = 2,246; unknown = 421). Eleven camera stations collected 8,625 exposures during the same period, with 5,511 of those photographs registering deer (64% of the total photographs). Other camera exposures included mammalian (2%), deer unknown (8%), misfires (23%), and other (4%).

After transformation, we obtained a nonsignificant result ($P = 0.125$) for Levene's Test of equal variance among treatment groups. The Kolmogorov-Smirnov test with Lilliefors significance modification revealed 2 of 16 treatment combinations to be non-normal (camera × winter × 1999 [$P = 0.23$], road × fall × 1999 [$P = 0.23$]). Because ANOVA is deemed robust to minor departures from normality, these treatments were included in the analysis.

We found road-survey estimates to be lower ($\bar{x} = 76$, SE = 6.45, $n = 48$) than ITC estimates ($\bar{x} = 166$, SE = 14.92, $n = 48$). The repeated-measures ANOVA results for between-subject effects (i.e., method) revealed a significant difference between the 2 methods ($P < 0.001$) but not between seasons ($P = 0.439$), and no method × season interactions occurred ($P = 0.963$; Fig. 2). The within-subject effects results indicated differences ($P = 0.046$) in density estimates between years and no year × method interaction ($P = 0.919$); however, we found a significant ($P = 0.004$) interaction between year × season. As a result, the estimates between seasons depend on the year of the survey. Finally, there was no year × method × season interaction ($P = 0.159$).

In comparing the proportion of marked deer between the 2 methods, we observed a higher ($P < 0.001$) proportion from road surveys ($\bar{x} = 0.266$, SE = 0.010, proportion of marked deer) than from ITC estimates ($\bar{x} = 0.146$, SE = 0.009, proportion of marked deer). Unlike the ITC estimates offering a more uniform sample of the island (Fig. 1), deer observations collected on the road survey also were biased towards urban roads. Approximately 79% of all deer observations were observed on urban roads, which comprised 63% of the survey route (Fig. 1).

Discussion

Road surveys have been the preferred method to estimate Key deer densities and/or monitor population trends by NKDR biologists for the last 30 years. All previous population data have been collected using road surveys due to their ease of application and the limited time and manpower available to conduct these surveys (Lopez et al. 2004*a*). In comparing road-survey estimates to ITC estimates, however, our study revealed a significant difference between the 2 methods for all seasons and years. Infrared-

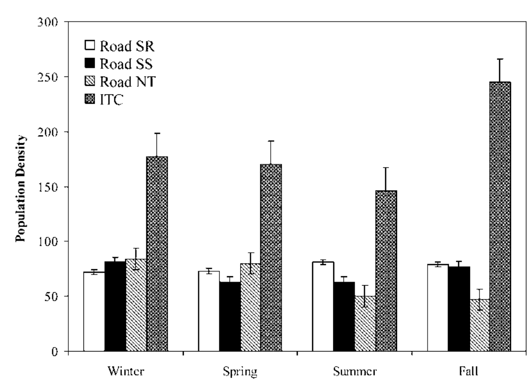

Figure 2. Florida Key deer density estimates (mean, SE) by season, time of day (sunrise = SR, sunset = SS, nighttime = NT), and method (road survey, infrared-triggered camera estimates [ITC]) for No Name Key (461-ha), Monroe County, Florida, USA, Jan 1999–Dec 2000.

triggered camera estimates were nearly 2 times those of road-survey estimates (Fig. 2). While our study did reveal the anticipated results, it also demonstrates that convenience sampling can easily bias survey results. We attribute differences in density estimates to biases in 1) the effective area sampled between methods, and 2) the proportion of marked animals observed between methods.

Spatial analysis of survey results found that 79% of road-survey observations occurred on urban roads (63% of the survey route), whereas ITC estimates were more uniformly distributed (Fig. 1). We propose that a more uniform coverage and use of nonbaited sites for the ITC surveys captured a larger portion of the spatial variability and was not as biased as the road surveys. Furthermore, urban roads in the northern area of island (Fig. 1) were improved, 2-lane, paved roads frequently driven by tourists and residents. Human–deer interactions were the greatest along these roadways (e.g., urban deer fed by tourists by roadways). Conversely, the rural roads in the southern area of island (Fig. 1) were unimproved, single-lane roads on bare limestone cap rock. Key deer were rarely observed along these roadways because animals were less domesticated (i.e., "wild" deer) and typically fled into the brush when a vehicle approached. Vehicle access into these areas is limited and restricted to the few rural roads providing access to NKDR lands. Use of road surveys would require that deer observations be obtained over a wider percentage of the island. The road-survey sampling design used in our study, however, was dictated by existing roadway infrastructure that was biased towards urban areas. The difference in the effective sampling area is a classic example of bias that often results from convenience sampling.

Another difference observed in our study was the proportion of marked animals observed between the 2 sampling methods. We found the proportion of marked animals observed on road surveys was nearly double those obtained from ITC data. As a result, density estimates from road-survey data were biased low (Krebs 1999). We attribute this difference to trapping methods used and deer behavior. First, many animals were trapped and collared in areas that were large enough for trapping procedures to take place (i.e., use of drop nets, Lopez et al. 1998), and as a result were often located close to the survey route. Likewise, in recent years Key deer have become urbanized in response to the abundance of food and fresh water in and around housing areas (Lopez et al. 2004*b*). In particular, Key deer have been observed to remain near roads due to the propensity of visiting tourists that feed deer from their vehicles (R. Lopez, Texas A&M University, personal observation). We propose that both of these variables have resulted in a biased road-survey sample due to an unequal distribution of marked deer. Collectively, we propose that the bias in sampling area and differences in sightability of marked deer between both methods accounts for population estimate differences observed in our study.

Management Implications

Our study demonstrates that ITC surveys can be used to carry out population estimates with fewer limitations inherent to road surveys. Road-survey estimates remain a viable method to estimate population numbers; however, biologists should be aware of potential biases. The use of ITC in estimating population numbers should also be applied with caution. Previous research with ITCs (Kucera et al. 1995, Jacobson et al. 1997, Koerth and Kroll 2000) were conducted using baited camera sites, which also may introduce unwanted bias in the estimates similar to our road surveys. Furthermore, the use of ITCs to monitor large areas may become cost-prohibitive or logistically impractical. For example, the costs in collecting road-survey data was approximately US$50/week (2 people, does not include vehicle, fuel, spotlights) compared to US$85/week for ITC surveys (1 person, 11 cameras; does not include vehicle, fuel, and ITC equipment, latter is a significant cost). Though the ITC surveys are more expensive, we suggest that these surveys can be cost-effective in the monitoring of the endangered Key deer on small, outer islands and in other areas where habitat and/or lack of infrastructure precludes the use of other methods. Currently, no viable alternatives exist to estimating Key deer densities on 16 outer islands because of a lack of roads. Estimating deer densities on islands throughout the range of the Key deer is required in the recovery plan (USFWS 1999). We uniformly placed cameras in our study area in obtaining our ITC estimates; future research should evaluate possible biases in such a sampling design versus a truly random design. We also recommend that natural markers (i.e., antler patterns, physical deformities/injuries) can be used in place of maintaining a marked deer herd for outer islands (Jacobson et al. 1997, Karanth and Nichols 1998, Heilbrun et al. 2002, Koerth and Kroll 2000).

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