Estimating Deer Abundance in Suburban Areas with Infrared-Triggered Cameras

Paul D. Curtis

Bazartseren Boldgiv

Peter M. Mattison

Jason R. Boulanger
University of North Dakota, jason.boulanger@und.edu

Human–Wildlife Conflicts 3(1):116–128, Spring 2009

Estimating deer abundance in suburban areas with infrared-triggered cameras

Paul D. Curtis, Cornell University, College of Agriculture and Life Sciences, Department of Natural Resources, 114 Fernow Hall, Ithaca, NY 14853, USA

Bazartseren Boldgiv,[1] Cornell University, College of Agriculture and Life Sciences, Department of Natural Resources, Ithaca, NY 14853, USA

Peter M. Mattison,[2] Cornell University, College of Agriculture and Life Sciences, Department of Natural Resources, Ithaca, NY 14853, USA

Jason R. Boulanger, Cornell University, College of Agriculture and Life Sciences, Department of Natural Resources, NY 14853, USA *jrb69@cornell.edu*

Abstract: Interactions between humans and white-tailed deer (*Odocoileus virginianus*) have become common, often resulting in management actions to mitigate negative impacts. Changes in population size are generally used to judge management actions. We examined deer population estimation techniques during 2 mark-resighting experiments in a woodland-grassland habitat in central New York State and in a suburban area. We compared program NOREMARK, Lincoln-Peterson estimates, and Jacobson's (1997) buck:doe ratios (BDR) for estimating deer abundance. In the first field trial, we sought to validate the camera survey methods and computer applications. We used infrared-triggered cameras (IRCs) to survey a white-tailed deer population of known size that inhabited a fenced, woodland-grassland area (11-day survey, 1 camera/33 ha, fall 1999). We estimated deer abundance with program NOREMARK (Bowden estimator). Analysis of the photographic data with this technique produced an accurate and precise population estimate in the first experiment. In the second experiment, we used program NOREMARK and 2 similar estimators in a previously untested suburban landscape. We surveyed a suburban white-tailed deer population with IRCs during spring and fall 2000 (10-day surveys, 1 camera/38 ha), using program NOREMARK (Bowden estimator), the Jacobson BDR method, and the Lincoln-Peterson estimator. All 3 methods produced similar estimates of deer abundance. We concluded that IRCs, in conjunction with either program NOREMARK or the Jacobson BDR method will provide reliable estimates of deer abundance in suburban areas.

Key words: camera traps, human–wildlife conflicts, mark-recapture, *Odocoileus virginianus,* population estimation, white-tailed deer

Today's resource managers face burgeoning populations of white-tailed deer (*Odocoileus virginianus*) in suburban areas and a concomitant increase in human–wildlife conflicts (DeNicola and Williams 2008, DeNicola et al. 2008). Knowing the abundance and distribution of deer is important for making population management decisions. Estimates of population size before and after a management action are used to judge the success of management programs (Lancia et al. 1994, Rutberg and Naugle 2008). However, accurate estimates of abundance are difficult to obtain, and management is often hindered by lack of confidence in census methods.

Because determining the actual number of deer in a population is difficult and expensive to ascertain (DeNicola et al. 2000), population size is generally estimated. Many methods have been used to determine deer abundance (Jacobson et al. 1997, McShea et al. 2008), but each method has its limitations. For example, aerial counts and thermal infrared photography may be expensive (Naugle et al. 1996), drive counts are labor-intensive (Wilson et al. 1996), and spotlight counts are restricted to open habitat (Fafarman and DeYoung 1986). Population reconstruction depends on reliable mortality data collected from hunter reports or other sources (Hesselton et al. 1965, Moen et al. 1986) that may not be available for many suburban areas. Population estimates from mark-recapture studies assume equal catchability; yet, many populations are heterogeneous in this characteristic (Pollock et al. 1990).

Instead of trapping animals individually

[1] Present address: National University of Mongolia, Ikh Surguuliin Gudamj 1, Ulaanbaatar 210646, Mongolia
[2] Present address: 5524 25th Avenue NE, Seattle, WA 98105, USA

for mark-recapture analyses, they can be recaptured by sightings. Mark-resighting offers advantages over conventional mark-recapture methods, including cost reduction, potential for recapture heterogeneity, and time savings (Minta and Mangel 1989). Mark-resighting has been tested with known populations of mule deer (*Odocoilues hemionus*; Bartmann et al. 1987), and applied to white-tailed deer (Rice and Harder 1977), mountain sheep (*Ovis canadensis*; Furlow et al. 1981, Neal et al. 1993), black and grizzly bears (*Ursus americanus* and *U. arctos horribilis*; Miller et al. 1987), and coyotes (*Canis latrans*; Hein and Andelt 1995).

Infrared-triggered cameras (IRCs) are a recent addition to resighting methods (Mace et al. 1994, Karanth and Nichols 1998, Grogan and Lindzey 1999) and have been useful in animal behavior studies (Carthew and Slater 1991). Roberts et al. (2006) demonstrated that IRC surveys could be used to conduct population estimates of deer with fewer limitations that are inherent in road surveys. An advantage to photographic data is that it allows more time to identify individuals that are uniquely marked. Moreover, IRCs are economically feasible and may be used with alternative sampling designs (Roberts et al. 2006).

Unmarked individual deer are often indistinguishable, except during fall and early winter when antlered bucks can be identified. Jacobson et al. (1997) used this characteristic and IRCs to estimate population size for white-tailed deer in rural woodlands. By comparing results to Lincoln-Petersen estimates, they concluded that the buck:doe ratio (BDR) method gave a close estimate of population size. The Jacobson BDR method also provided a reasonable estimate of white-tailed deer abundance in a grassland-scrub habitat in southern Texas (Koerth et al. 1997).

Another recent advance in population estimation techniques was the development of the computer program NOREMARK (White 1996). This program provides abundance estimates from mark-resighting data, including photographs, and does not assume equal catchability. This method has been used for coyotes (Hein and Andelt 1995), black bears (Grogan and Kindzey 1999), and feral hogs (*Sus scrofa*; Sweitzer et al. 2000).

Our objectives were to (1) assess whether IRC data analyzed with the program NOREMARK could be used to estimate accurately and precisely white-tailed deer abundance for a population of known size, (2) evaluate this technique for estimating population size for a suburban deer herd, and (3) compare the reliability of the Jacobson et al. (1997) BDR method with program NOREMARK and Lincoln-Petersen estimates of abundance for the same suburban deer population.

Materials and methods

Experiment 1: Method validation at Seneca Army Depot

The camera survey for deer was conducted in the Quarantine Area (QA), a 263-ha enclosure at the northern end of the 4,000-ha Seneca Army Depot (SEAD), near Romulus, New York, USA. The QA was enclosed by 3 parallel 2.4-m-high security fences and comprised 78% open grasslands, 17% woodlots, and 5% paved roads, railroads, and buildings. The QA provided a rare opportunity to create our own research herd with almost no exchange (1 exception) inside and outside the enclosure. The QA contained 137 free-ranging, white-tailed deer, with 104 of them marked and 33 unmarked. We determined the number of unmarked deer inside the fence at the time of the survey by establishing semi-permanent blinds near bait piles at several sites in open fields. Researchers and student interns logged thousands of hours watching deer with spotting scopes each summer to confirm which does had fawns and how many. The marked deer had been captured from the surrounding SEAD with rocket nets (Hawkins et al. 1968), dart guns (Pneu Dart, Inc., Williamsport, Pa.), and Clover traps (Clover 1956), and released within the QA between spring 1996 and winter 1998 (Pooler 2001). These deer had been marked at capture with numbered, aluminum ear tags and numbered, color-coded collars (Pooler 2001). There was no hunting on the QA during this study. All research conformed to the requirements of Cornell University's Institutional Animal Care and Use Committee and New York State Department of Environmental Conservation Special Licenses Unit.

We conducted the camera survey daily from September 15 to 25, 1999. We confirmed that this period was adequate by monitoring cumulative catch rates and population estimates obtained after each day. We used the TRAILMASTER® IRC system (Goodson and Associates, Inc., Lenexa, Kan.), which included TM550 passive infrared trail monitors, and TM35-1 camera kits. Each camera featured automatic flash and film advance, and data back memory listing exposure date and time. The TM550 detects movement of warm-blooded animals; it is a weatherproof sensing device with an elliptical sensitivity cone about 19.5 m deep, 150° wide, and 4° high. At each station, the camera and monitor were mounted on metal poles or trees 6–8 m from bait. The IRCs faced north or south to avoid overexposure of photos near dawn and dusk. We positioned the infrared monitor approximately 0.75 m above the ground and the camera about 0.25 m directly above it. We reduced the width of the monitor's detection field to approximately 30˚ by partially blocking the sensor with black tape. This ensured IRCs would not be activated until the target animals were in the photographic field. Sensitivity of the trail monitor was set at the manufacturer's recommended setting of 5. The photographic interval was set to 4 minutes to balance our desire to reduce consecutive photographs of the same individual, with the risk of missing animals (Koerth and Kroll 2000). We denoted each site with a different reflective number on a stake within the camera's field of view so that the reference number appeared in all photographs.

We used a camera density of 1 per 33 ha to approximate the density used by Koerth et al. (1997). We achieved this camera density by dividing our study areas into 8 equal sections. Near the center of each section, we created a bait station containing 20–25 kg of whole and pressed apples. We cleared low-lying vegetation within a 20-m radius of the bait to facilitate deer identification in photographs. We began the camera survey after an 8-day pre-baiting period. We excluded photographs of insufficient quality (i.e., those with fog or flare on the lens, etc.) for analysis. We visited each camera station daily between 0900–1400 hr for equipment, bait, and film (35 mm, ISO 200, 36-exposure color print) maintenance.

We analyzed capture data with program NOREMARK (White 1996). This program accounts for our inability to identify all marked animals. We obtained the date and the numbers of marked, unmarked, and marked but unidentifiable deer from each photograph. We used both an 8x magnifying loupe and a magnifying work light to identify deer in the photographs. Program NOREMARK includes the count for tagged but unidentifiable deer in the population estimate. We placed deer that we could not determine whether or not they were tagged (i.e., partial deer visible) in an "unknown" category and excluded those deer from the analysis.

Of the 4 estimators available in NOREMARK, we used the Bowden estimator (Bowden 1993) for the Minta-Mangel model (Minta and Mangel 1989). This estimator does not require that each animal in the population have the same probability of resighting, but does assume that the population is closed (White 1996). The Bowden estimator (Minta-Mangel model) and confidence intervals were based on the variance from the resighting frequencies of the marked animals.

Experiment 2: Field trial in Cayuga Heights

This experiment compared deer abundance using IRC data for 3 independent estimators: program NOREMARK, the BDR method (Jacobson et al. 1997), and the Lincoln-Petersen Index (Overton 1969). To conduct the mark-resighting analyses, we captured and marked 50 deer from January 23 to March 12, 2000, and completed both spring and fall camera surveys.

The Village of Cayuga Heights is located in the Town of Ithaca, Tompkins County, New York, USA. Cayuga Heights is an affluent community bordering the City of Ithaca and Cornell University (Chase et al. 1999). Census figures indicated that the village had 3,188 residents in 2000 (U.S. Census Bureau 2003), and Tompkins County Office of Real Property Tax Assessment listed 851 residential properties. The village covers 458 ha ranging from 137 to 274 m above sea level along the east shore of Cayuga Lake. Cayuga Heights had numerous woodlots covering side slopes and ravines, which provided habitat and travel corridors for deer. Using the National Land Cover Dataset (Vogelmann et al. 2001), we determined that

Cayuga Heights was composed primarily of developed land (83%; open space and low to high intensity), followed by forested land (9%; deciduous, coniferous, and mixed) and woody and emergent herbaceous wetlands (7%). In 2 surveys of Cayuga Heights residents, respondents expressed concern over deer-related auto accidents, damage to plantings, and Lyme disease (Shanahan et al. 2001). Over 80% of respondents reported damage to flower gardens, trees, and shrubs; 23–25% of respondents reported experience with deer-related auto accidents (Shanahan et al. 2001). Cayuga Heights regulations and community ordinances prohibit firearm discharge, and the community is completely closed to hunting.

We captured the first 33 deer in 16 Clover traps in the backyards of cooperating landowners. Traps were baited with corn, whole apples, and pressed apples. To increase capture success, we kept traps open for 3–5 days prior to setting them to habituate deer to the traps. We set traps each evening at dusk and checked the following morning. During the day, traps were wired open to avoid deer capture and potential conflicts with humans or domestic animals. Captured deer were handled, marked, and released on site each day before 0900 hr. We captured 17 additional deer with rocket nets beginning February 8, 2000 (Hawkins et al. 1968).

We gave deer in captured Clover traps and rocket nets an intramuscular injection (0.5 ml for fawns and 1.0 ml for yearlings or adults) of xylazine hydrochloride (Rompun; Miles Laboratories, Shawnee Mission, Kan.) for immobilization. The deer were usually immobile after 5–7 minutes of being injected, at which point they were removed from the netting; their legs were bound with rope to prevent injury from involuntary movement or premature recovery. We recorded sex, approximate age (by tooth wear; Larson and Taber 1980), and capture location.

We double-marked 33 deer with cattle ear-tags and an alpha-numeric collar. The ear tags were consecutively numbered. We marked an additional 17 adult female deer with both ear tags and radio collars to monitor survivorship and estimate the number of deer alive in the community during fall. After marking the deer, we injected them with yohimbine hydrochloride (Yobine; Lloyd Laboratories, Shenandoah, Ia.) intravenously to reverse the immobilizing drug. We left the deer in natural bedding positions to allow regular blood circulation and later checked to confirm their full recovery.

Following the same protocol as for Experiment 1, we conducted a 10-day camera survey during spring and another during the fall of 2000. The spring survey occurred during March 22 to 31, and the fall survey occurred from September 29 to October 8. We confirmed that these time periods were adequate by monitoring cumulative catch rates and population estimates obtained after each day.

We divided the study area into 12 equal sections, resulting in a camera density of 1 per 38 ha. We positioned IRCs at sites with high deer activity, such as wooded strips between houses and along ravines and hedges. We baited the sites with whole-kernel corn (15–20 kg) supplemented with pressed apples in the fall for both surveys. Three of the stations produced low photo-recapture rates in the spring, so we relocated the IRCs within the same 38-ha sections for the fall survey.

As in Experiment 1, we collected all data from the photographs and used the NOREMARK program with the Bowden estimator for the Minta-Mangel model (White 1996) for spring and fall population estimates. We knew the number of marked deer in Cayuga Heights for the spring camera survey because it was conducted only 10 days after we finished trapping. However, we did not know the exact number of marked deer during the fall survey. Several marked deer had died, and others had left the study area before the fall survey. Therefore, we had to estimate the number of marked deer remaining in the village to analyze the fall camera survey data and perform the Lincoln-Petersen calculations. To estimate the number of marked deer remaining, we took the proportion of known versus unknown radio-collared deer and extrapolated to the marked, non-radio-collared deer. In the multiple-occasion, mark-recapture method (Pollock et al. 1990), an average estimator of the number of marked deer (M_i) is calculated from capture history of all individuals. We could not use this method because the capture history of unmarked deer was unknown. Instead, we used the proportion of radio-collared deer captured on film to estimate the total number of marked deer present during the fall survey, as follows:

$$M_i = m_p + \frac{(N_{T,N} \times N_{C,P})}{N_{T,P}} ,$$

where m_p = a total number of marked deer photographed during survey period, $N_{T,N}$ = number of radio-collared deer not photographed, but present in the study area, $N_{C,P}$ = number of alpha-numeric-collared deer, and $N_{T,P}$ = number of radio-collared deer photographed during camera survey period.

We examined potential bias resulting from capture method and whether this differed between sexes by comparing the number of deer of each sex captured in Clover traps or rocket nets, with the number recaptured at camera sites (Jacobson et al. 1997). This information was also necessary for testing the assumption of equal catchability for Jacobson et al. (1997) BDR estimator and the Lincoln-Peterson Index.

We used the Jacobson et al. (1997) BDR method for estimating population size from the fall survey data. We identified individual branch-antlered bucks (those possessing 1 or 2 branched antlers) by antler configuration and body traits. We estimated the number of spike-antlered bucks from the spike:branch ratio,

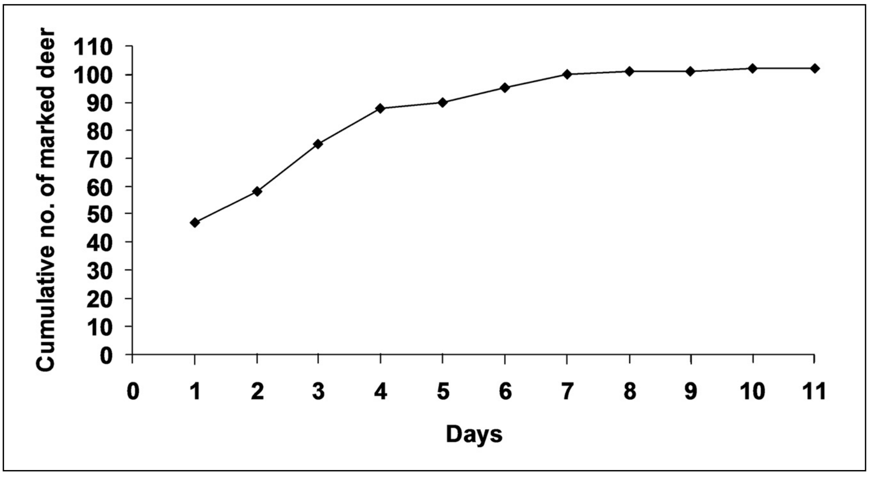

Figure 1. Cumulative catch rates for marked deer using infrared-triggered cameras in the Seneca Army Depot site, Romulus, New York, during September 15–25, 1999.

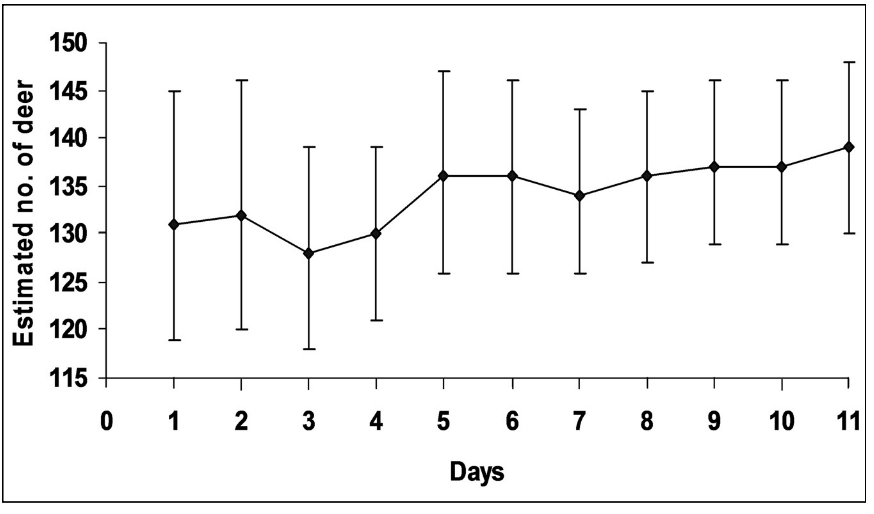

Figure 2. Daily estimates for the number of deer present in Quarantine Area at Seneca Army Depot site, Romulus, New York, during September 15–25, 1999. Vertical bars indicate 95% CI.

the number of females was estimated from the doe:buck ratio, and the number of fawns from the fawn:doe ratio. Total population size was the sum of estimates for each sex and age class.

The Lincoln-Petersen Index provided estimates of deer abundance during both spring and fall camera surveys. We calculated cumulative Lincoln-Petersen estimates and 95% confidence intervals using Overton's (1969) equations. We calculated a mean Lincoln-Petersen estimate at the end of each 10-day session. We used Fisher's exact test (Sokal and Rohlf 1969) to evaluate effect of sex and initial capture techniques on photographic recapture of marked deer at baited sites. Both Jacobson's BDR method, and the Lincoln-Petersen estimate, assumed a closed population and equal catchability. The Lincoln-Peterson index also assumed that marks were not lost or gained (Pollock et al. 1990).

Results

Seneca Army Depot

At SEAD, we obtained 1,238 photographs of deer, which included observations of 2,230 marked and 750 unmarked deer. We photographed a total of 102 of the 104 marked deer (98%) by Day 10 (Figure 1). The median population estimate was 136 deer (95% CI = 126–146) using the Bowden estimate for the Minta-Mangel model (Figure 2), which was close to the actual population size (137 deer) in the 263-ha enclosure. The cumulative daily population estimate varied little after 5 days of the IRC survey (Figure 2). This was an ideal situation for validating the computer simulations, as all model assumptions were satisfied. It was nearly impossible for deer to leave the triple-fenced research enclosure, so the population was closed as required for Bowden's estimator (White 1996). Also, there were no births or known mortalities in the enclosure during the 11-day survey period; consequently, population size was constant. Finally, the cumulative catch rate had stabilized by Day 7 of photo-sampling (Figure 1), indicating most (98%) marked deer in the herd had been recorded on film.

Cayuga Heights

In Cayuga Heights, we obtained 1,126 photographs, which included observations of 853 marked and 1,574 unmarked deer (Table 1). We rejected 174 photographs of insufficient quality. Forty-five of the 50 deer we marked were alive during the spring survey, and 42 (93%) of them were photographed. There was no sex bias in recapture rates; 18 (95%) of the 19 males and 24 (92%) of the 26 females were photographed (Fisher's exact test, $P = 1.0$).

The cumulative catch rate stabilized by Day 6 (Figure 3a). The Bowden estimator and Lincoln-Petersen Index provided similar estimates of population size on Day 6 and on Day 10 (Figure 4). On Day 10, the Bowden estimator showed that there were 124 (95% CI = 120–137) deer present in Cayuga Heights. The final population

Table 1. Deer population estimates for Cayuga Heights, New York, in March–April and September–October 2000 from infrared-triggered cameras.

Estimation method	Estimated parameters
Spring 2000 survey	1,126 photographs
Population estimates	
Ratio of marked and unmarked deer on photos	853:1,574
Bowden's ratio estimator (95% CI)	124 (104–148)
Lincoln-Petersen estimator (95% CI)	126 (120–137)
Fall 2000 survey	1,566 photographs
Buck:doe ratio	1:3.744
Doe:fawn ratio	1:1.038
Branched:spike ratio	1:0.079
No. branch-antlered males	15
Ratio of marked and unmarked deer on photos	347:1,887
Population estimates	
Buck:doe ratio method (Jacobson et al. 1997)	147
Bowden's ratio estimator (95% CI)	141 (81–234)
Lincoln-Petersen estimator (95% CI)	152 (133–166)

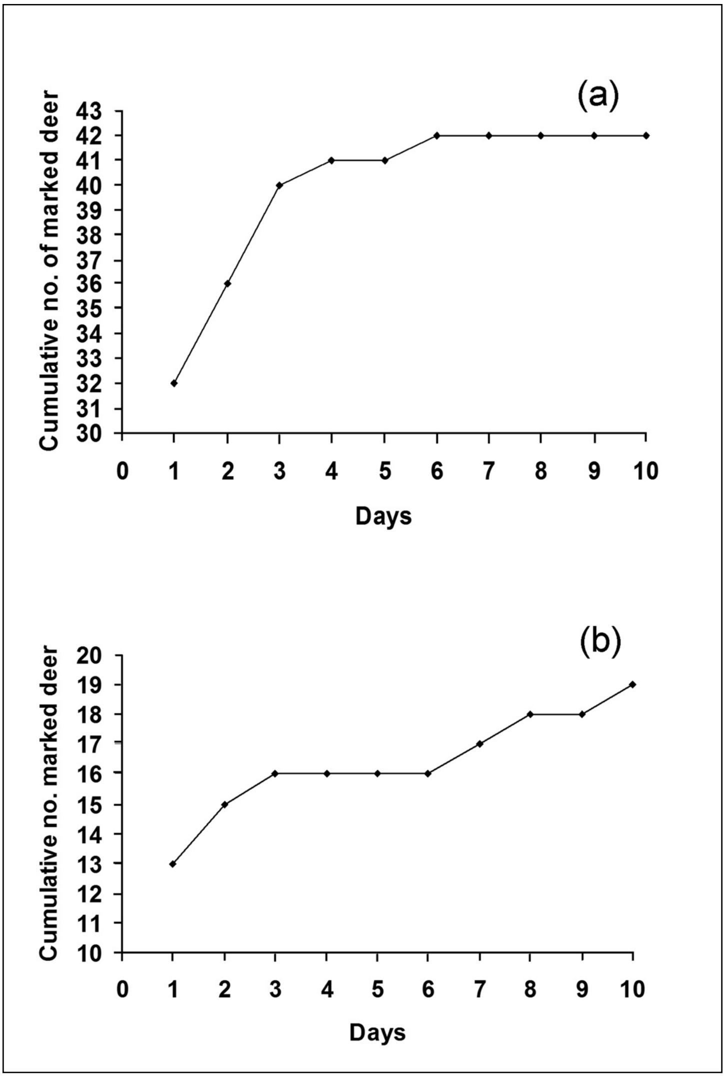

Figure 3. Cumulative catch rates for marked deer using infrared-triggered cameras in the Village of Cayuga Heights, New York, during March 23–31 (a), and September 29–October 8, 2000 (b).

estimate from the Lincoln-Petersen Index was 126 deer (Table 1).

A total of 1,566 photographs was obtained during the fall camera survey in Cayuga Heights, including observations of 347 marked and 1,887 unmarked deer (Table 1). We rejected 231 illegible photographs due to partial deer images, false triggers, and lense fogging. We identified 15 different branch-antlered and 2 spike bucks from the photographs. The cumulative catch rate increased throughout the 10-day period of camera trapping (Figure 3b), but the estimate of abundance was similar after Day 7 (Figure 5).

We found no difference among sex ratios for photographed deer, whether they were initially captured in Clover traps or in rocket nets (Fisher's exact test, P = 0.525). Males and females were considered to be equally attracted to camera sites regardless of their initial capture method.

Discussion

To estimate white-tailed deer abundance in woodland areas, Jacobson et al. (1997) conducted 2, 14-day surveys with IRCs, at 3 camera sites. The highest camera density (1/65 ha) gave the most accurate estimate, and > 80% of marked deer were captured on film in ≤10 days. Koerth et al. (1997) used a camera density of 1/33 ha and a 10-day survey period to estimate white-tailed deer abundance in a grassland-scrub habitat with Jacobson et al.'s (1997) method. Consequently, we used a high camera density (1/33 ha or 1/38 ha) and shorter survey period to maximize the reliability of our survey. The smaller size of our study areas (SEAD = 263 ha; Cayuga Heights = 458 ha) compared to those of Jacobson et al. (1997; 4,047 ha) and Koerth et al. (1997; 1,055 ha) made the high camera density economically feasible.

There was minimal variation in deer abundance derived from the 3 estimators during the fall survey. The lowest estimate (141) was provided by the Bowden model, and the highest (152) by the Lincoln-Peterson Index. The BDR method (Jacobson et al. 1997) indicated a population size of 147. There was little chance of deer mortalies or movement in or out of the study area during the camera survey because the time period was short (Pollock et al. 1990). Similarity of the abundance estimates produced by the 3 independent analyses provided evidence that closure assumption was met and the estimates were reliable.

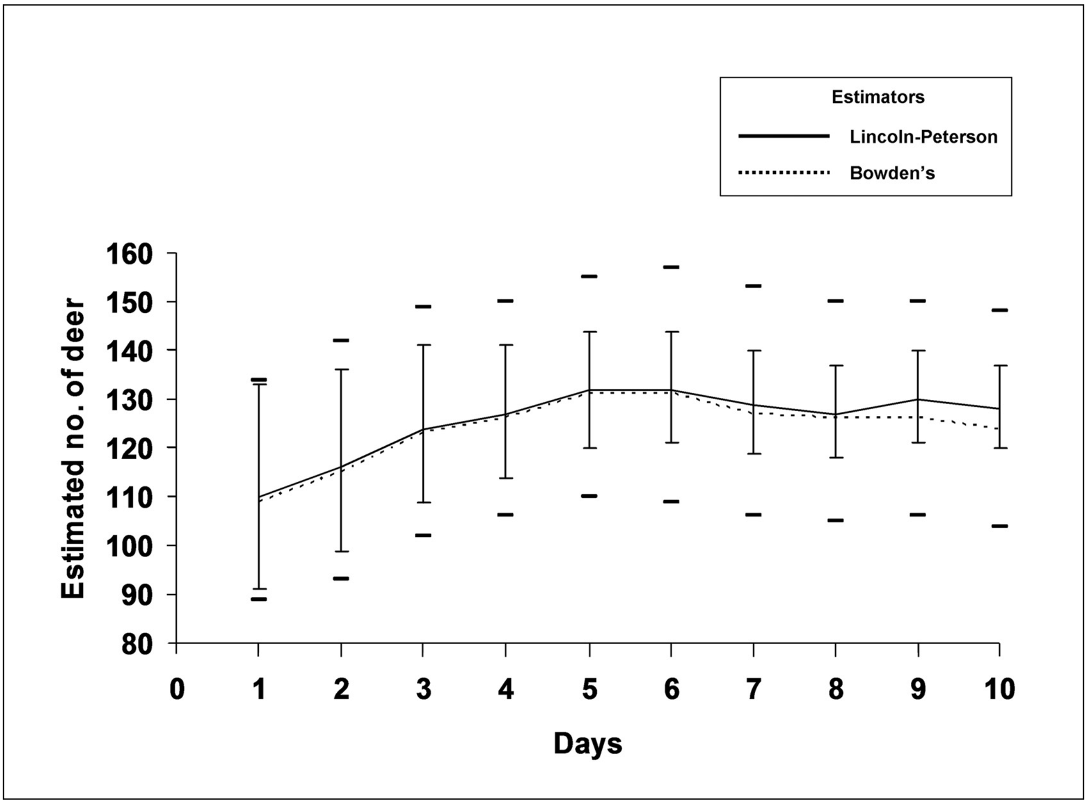

Figure 4. Daily estimates for the number of deer present in the Village of Cayuga Heights, New York, during a 10-day period, March 22–31, 2000, based on Bowden's and Lincoln-Petersen estimators from photographic recapture data. Horizontal bars indicate 95% CI for Bowden's estimator, and vertical bars indicate 95% CI for Lincoln-Petersen estimator.

The percentages of marked animals that were captured on film during the surveys at SEAD (98%) and Cayuga Heights (93%) were similar to those obtained by Jacobson et al. (1997) during 1992 (88%) and 1993 (100%). The double-marking system of ear tags and collars facilitated identification of marked deer during photo-recapture and direct spotting, as it allowed deer to be identified frontally or in profile. The cumulative catch usually stabilized sooner during our surveys (Days 5–7) than for Jacobson et al.'s (1997; Day 10 or later). This presumably reflects the higher camera densities we used (1/33 and 1/38 ha) compared to those used by Jacobson et al. (1997). Higher camera densities may, therefore, reduce the overall time needed to obtain adequate sample sizes, reducing costs for fuel, bait, and labor.

Deer at both SEAD and Cayuga Heights were habituated to people and readily attracted to bait sites. It may take longer for deer that are less accustomed to humans or bait to be attracted to bait at the camera sites. Camera surveys in rural areas may need to continue for longer periods to obtain a sufficient sample of photographs and recapture a high percentage of marked deer. Baiting deer remains controversial because of the potential for disease transmission (Williamson 2000) and because bait sites may attract deer from distant areas. Roberts et al. (2006) suggested that non-baited camera surveys may alleviate sample bias and may be suitable for areas where other survey estimate types are not available. Van Brackle et al. (1995) reported that white-tailed deer travelled up to 5.4 km to feed on bait. In contrast, Kilpatrick and Stober (2002) and Campbell et al. (2006) reported comparable core-area and home-range sizes between baiting and non-baiting periods among white-tailed deer. In the latter studies, deer shifted their core areas closer to bait sites during baiting periods.

Jacobson et al. (1997) found that the ratio of antlered bucks to does captured on film

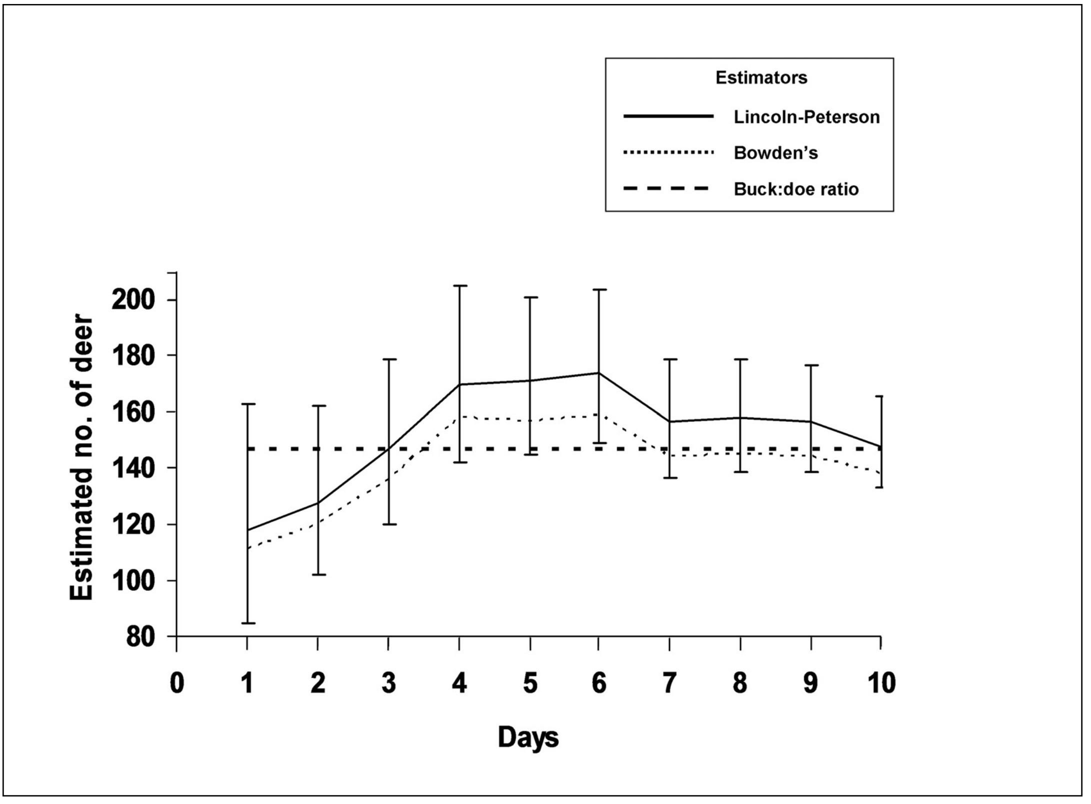

Figure 5. Daily estimates for the number of deer present in the Village of Cayuga Heights, New York, during a 10-day period during September 29–October 8, based on the buck:doe ratio method (Jacobson et al. 1997), Bowden's and Lincoln-Petersen estimators from photographic recapture data. Vertical bars indicate 95% CI on Lincoln-Petersen estimator.

increased with increasing camera density, with ratios of 40% bucks in 1992 and 58% bucks in 1993 at the highest camera density (1/65 ha). Koerth et al. (1997) obtained a buck:doe ratio of 53% in their camera survey. In our study, only 21% of the deer captured on film were bucks. Jacobson et al.'s (1997) study population was managed for production and harvest of mature bucks, which would account for their higher percentage of males. We documented average dispersal distances for yearling male deer in Cayuga Heights of about 12 km (Boldgiv 2001). While dispersal distance is not critical for estimates of abundance, it is important to know which deer dispersed out of the community and when to determine the number of tagged deer available for camera surveys. Thus, deer sex ratios in the community are influenced by interchange with deer from surrounding areas.

There are many benefits to the IRC technique. It requires no recapture and handling of animals, which reduces trap-shyness. Most estimation procedures are based on the assumption of equal catchability, which may be violated with standard trapping methods (Minta and Mangel 1989, Pollock et al. 1990). Secondly, an adequate sample size can be obtained in a short time because large areas can be sampled, and all animals are simultaneously and continuously detectable (Mace et al. 1994). The camera technique gathers information on sex and basic age ratios of deer (Koerth et al. 1997), which aerial surveys do not. Finally, photographs may serve other purposes, such as marketing and advertising management programs (Koerth et al. 1997).

The primary disadvantage of IRC sampling was cost. The equipment was expensive and vulnerable to theft or human interference, which limits potential camera locations. For our 11-day camera survey at SEAD at 1 camera per 33 ha, our total costs were $6,951, or $26/ha. This comprised $1,555 for 8 infrared monitors ($194 each), $2,506 for 8 cameras ($313 each), $550 for 34 rolls of film with processing, and $2,340 for a month of staff time at $15 per hour.

If the life expectancy of the equipment was 5 years, costs would be $14/ha/yr. Digital IRCs have since become commonplace. As a result, costs and life expectancy of equipment may differ today.

Jacobson et al. (1997) and Koerth et al. (1997) quote costs for their camera surveys of $5/ha (for highest camera density) and $2/ha, respectively. The higher cost of our survey was probably due to our including expense categories (e.g., staff time) that were excluded from other estimates. Expense comparison among different survey methods was difficult because costs were not reported uniformly or in sufficient detail. The camera method may be more costly than visual helicopter surveys. Koerth et al. (1997) noted that the cost of surveying their study area by helicopter (excluding travel costs) would have been half the expense of their camera survey. Belant and Seamans (2000) stated a cost of $0.25/ha for pilot and helicopter hire in their surveys. Adding thermal infrared sensing to an aerial survey increased the cost to $1/ha (Naugle et al. 1996). The expense of using IRCs can be justified when seeking accurate and reliable population estimates or detailed information on herd sex and age ratios, for measuring success of management programs (Lancia et al. 1994) or studying population dynamics.

Our Cayuga Heights study showed that Jacobson et al.'s (1997) BDR method for estimating deer abundance, which had been successfully applied to both a forested habitat (Jacobson et al. 1997) and a grassland-scrub habitat (Koerth et al. 1997), can be applied in suburban areas, as well. The primary advantage of Jacobson's method is that individual deer do not have to be captured and marked, saving considerable time and expense. A disadvantage is that this technique can be used only when bucks have antlers (i.e., fall to mid-winter), and the quality of photographs must be sufficient to distinguish branch-antlered males from each other. The BDR method also provides no error term (confidence interval). We recommend that if deer can be surveyed in the fall, Jacobson's method should be used to minimize animal handling, time, and cost.

We confirmed that IRCs and the Bowden estimator for the Minta-Mangel model (program NOREMARK) provided reliable estimates of deer abundance in both the grassland-woodland habitat of SEAD and a developed suburban landscape. For suburban surveys that must occur when male deer do not have antlers, we recommend using program NOREMARK with tagged deer, as this estimator was designed to accommodate photographic data.

As burgeoning white-tailed deer populations negatively impact urban, suburban, and exurban landscapes, the demand for innovative control measures will increase (Hussain et al. 2007, Storm et al. 2007). In particular, deer–vehicle collisions have become a serious problem (Bissonette et al. 2008, Grovenburg et al. 2008, Mastro et al. 2008, Ng et al. 2008). For any population control method (e.g., sharpshooting or fertility control), wildlife managers will need quality baseline information regarding deer abundance, age, and sex ratios. Traditional population survey techniques are not always practical in urban or suburban wildlife studies. IRCs have advantages over aerial surveys and ground drives in populous areas as the camera surveys are quiet, unobtrusive, and obtain data at all hours (Wilson et al. 1996). The IRC method may be the most suitable technique for studies of urban wildlife where it is difficult to otherwise measure animal abundance.

Acknowledgments

Funding for this study was provided by the Open Society Institute. M. E. Richmond, USGS-New York Cooperative Fish and Wildlife Research Unit, provided valuable guidance and support. The study was conducted in cooperation with New York State Department of Environmental Conservation, the Department of Defense-Seneca Army Depot, and the Village of Cayuga Heights. P. Moon, and F. W. Quimby, Cornell College of Veterinary Medicine, provided advice on deer immobilization. M. Stofka and S. Absalom (SEAD) provided access to military property and history of the deer population at SEAD. E. G. Cooch assisted with statistical analysis. G. B. Curtis and E. D. Rowland helped with various aspects of the field study.

Literature cited

Bartmann, R. M., G. C. White, L. H. Carpenter, and R. A. Garrot. 1987. Aerial mark-recapture estimates of confined mule deer in pinyon-juniper woodland. Journal of Wildlife Management 51:41–46.

Belant, J. L., and T. W. Seamans. 2000. Comparison of 3 devices to observe white-tailed deer at night. Wildlife Society Bulletin 28:154–158.

Bissonette, J. A., C. A. Kassar, and L. J. Cook. 2008. Assessment of costs associated with deer–vehicle collisions: human death and injury, vehicle damage, and deer loss. Human–Wildlife Conflicts 2:17–27.

Boldgiv, B. 2001. Estimation of abundance and movement patterns for white-tailed deer (*Odocoileus virginianus*) in Cayuga Heights, New York. Thesis, Cornell University, Ithaca, New York, USA.

Bowden, D. C. 1993. A simple technique for estimating population size. Department of Statistics, Colorado State University, Fort Collins, Colorado, USA.

Campbell, T. A., C. A. Langdon, B. R. Laseter, W. M. Ford, J. W. Edwards, and K. V. Miller. 2006. Movements of female white-tailed deer to bait sites in West Virginia, USA. Wildlife Research 33:1–4.

Carthew, S. M., and E. Slater. 1991. Monitoring animal activity with automated photography. Journal of Wildlife Management 55:689–692.

Chase, L. C., W. F. Siemer, and D. J. Decker. 1999. Designing strategies for stakeholder involvement in wildlife management: insights from case studies in Colorado and New York. Human Dimensions Research Unit. Series publication 99-9. Cornell University, Ithaca, New York, USA.

Clover, M. R. 1956. Single-gate deer trap. California Fish and Game 42:199–201.

DeNicola, A. J., D. R. Etter, and T. Almendinger. 2008. Demographics of non-hunted white-tailed deer populations in suburban areas. Human–Wildlife Conflicts 2:102–109.

DeNicola, A. J., K. C. VerCauteren, P. D. Curtis, and S. E. Hygnstrom. 2000. Managing white-tailed deer in suburban environments: technical guide. Cornell Cooperative Extension Information Bulletin 245. Cornell University, Ithaca, New York, USA.

DeNicola, A. J., and S. C. Williams. 2008. Sharpshooting suburban white-tailed deer reduces deer–vehicle collisions. Human–Wildlife Conflicts 2:28–33.

Fafarman, K. R, and C. A. DeYoung. 1986. Evaluation of spotlight counts of deer in south Texas. Wildlife Society Bulletin 13:146–149.

Furlow, R. C., M. Haderlie, and R. Van den Berge. 1981. Estimating a bighorn sheep population by mark-recapture. Desert Bighorn Council Transactions 1981:31–33.

Grogan, R. G., and F. G. Lindzey. 1999. Estimating size of a low-density black bear population. Ursus 11:117–122.

Grovenburg, T. W., J. A. Jenks, R. W. Klaver, K. L. Monteith, D. H. Galster, R. J. Schabuer, W. W. Morlock, and J. A. Delger. 2008. Factors affecting road mortality of white-tailed deer in eastern South Dakota. Human–Wildlife Conflicts 2:48–59.

Hawkins, R. E., L. D. Martoglio, and G. G. Montgomery. 1968. Cannon-netting deer. Journal of Wildlife Management 32:191–195.

Hein, E. W., and W. F. Andelt. 1995. Estimating coyote density from mark-resight surveys. Journal of Wildlife Management 59:164–169.

Hesselton, W. T., C. W. Severinghaus, and J. E. Tanck. 1965. Population dynamics of deer at Seneca Army Depot. New York Fish and Game Journal 12:17–30.

Hussain, A., J. B. Armstrong, D. B. Brown, and J. Hogland. 2007. Land-use pattern, urbanization, and deer–vehicle collisions in Alabama. Human–Wildlife Conflicts 1:89–96.

Jacobson, H. A., J. C. Kroll, R. W. Browning, B. H. Koerth, and M. H. Conway. 1997. Infrared-triggered cameras for censusing white-tailed deer. Wildlife Society Bulletin 25:547–556.

Karanth, K. U., and J. D. Nichols. 1998. Estimation of tiger densities in India using photographic captures and recaptures. Ecology 79:2852–2862.

Kilpatrick, H. J., and W. A. Stober. 2002. Effects of temporary bait sites on movements of suburban white-tailed deer. Wildlife Society Bulletin 30:760–766.

Koerth, B. H., and J. C. Kroll. 2000. Bait type and timing for deer counts using cameras triggered by infrared cameras. Wildlife Society Bulletin 28:630–635.

Koerth, B. H., C. D. McKown, and J. C. Kroll. 1997. Infrared-triggered camera versus helicopter counts of white-tailed deer. Wildlife Society Bulletin 25:557–562.

Lancia, R. A., J. D. Nichols, and K. H. Pollock. 1994. Estimating the number of animals in wildlife populations. Pages 215–253 *in* T. A. Bookhout, editor. Research and management techniques for wildlife and habitats. Fifth edition. The Wildlife Society, Washington, D.C., USA.

Larson, J. S., and R. D. Taber. 1980. Criteria of sex and age. Pages 143–202 *in* S. D. Schemnitz, editor. Wildlife techniques manual. Fourth edition. The Wildlife Society, Washington, D.C., USA.

Mace, R. D., S. C. Minta, T. L. Manley, and K. E. Aune. 1994. Estimating grizzly bear population size using camera sightings. Wildlife Society Bulletin 22:74–83.

Mastro, L. L., M. R. Conover, and S. N. Frey. 2008. Deer–vehicle collision prevention techniques. Human–Wildlife Conflicts 2:80–92.

McShea, W. J., C. M. Stewart, L. J. Kearns, S. Liccioli, and D. Kocka. 2008. Factors affecting autumn deer–vehicle collisions in a rural Virginia county. Human–Wildlife Conflicts 2:110–121.

Miller, S. D., E. F. Becker, and W. H. Ballard. 1987. Black and brown bear density estimates using modified capture-recapture techniques in Alaska. International Conference on Bear Research and Management 7:23–35.

Minta S., and M. Mangel. 1989. A simple population estimate based on simulation for capture-recapture and capture-resight data. Ecology 70:1738–1751.

Moen, A. N., C. W. Severinghouse, and R. A. Moen. 1986. Deer CAMP: computer assisted management program. Cornerbrook Press, Lansing, New York, USA.

Naugle, D. E., J. A. Jenks, and B. J. Kernohan. 1996. Use of thermal infrared sensing to estimate density of white-tailed deer. Wildlife Society Bulletin 24:37–43.

Neal, A. K., G. C. White, R. B. Gill, D. F. Reed, and J. H. Olterman. 1993. Evaluation of mark-resight model assumptions for estimating mountain sheep numbers. Journal of Wildlife Management 57:436–450.

Ng, J. W., C. Nielsen, and C. C. St. Clair. 2008. Landscape and traffic factors influencing deer–vehicle collisions in an urban environment. Human–Wildlife Conflicts 2:34–47.

Overton, W. S. 1969. Estimating the numbers of animals in wildlife populations. Pages 403–455 *in* R. H. Giles, editor. Wildlife management techniques. Third edition. The Wildlife Society, Washington D.C., USA.

Pollock K. H., J. D. Nichols, C. Brownie, and J. E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs 107:1–97.

Pooler, R. L. 2001. Immunocontraceptive vaccines for controlling reproduction in white-tailed deer: assessment of cost, efficacy, and behavioral effects. Thesis, Cornell University, Ithaca, New York, USA.

Rice, W. R., and J. D. Harder. 1977. Application of multiple aerial sampling to a mark-recapture census of white-tailed deer. Journal of Wildlife Management 41:197–206.

Roberts, C. W., B. L. Pierce, A. W. Braden, R. R. Lopez, N. J. Silvy, P. A. Frank, and D. Ransom Jr. 2006. Comparison of camera and road survey estimates for white-tailed deer. Journal of Wildlife Management 70:263–267.

Rutberg, A. T., and R. E. Naugle. 2008. Deer–vehicle collision trends at a suburban immunocontraception site. Human–Wildlife Conflicts 2:60–67.

Shanahan, J. E., W. F. Siemer, and A. F. Pleasant. 2001. Community attitudes about deer management in the Village of Cayuga Heights, New York. Human Dimensions Research Unit Series Publication 01-7. Department of Natural Resources, Ithaca, New York, USA.

Sokal, R. R. and F. J. Rohlf. 1969. Biometry. Freeman, San Francisco, California, USA.

Storm, D. J., C. K. Nielsen, E. M. Schauber, and A. Woolf. 2007. Deer–human conflicts and hunter access in an exurban landscape. Human–Wildlife Conflicts 1:53–59.

Sweitzer, R. A., D. Van Vuren, I. A. Gardner, W. M. Boyce, and J. D. Waithman. 2000. Estimating sizes of wild pig populations in the north and central coast regions of California. Journal of Wildlife Management 64:531–543.

U.S. Census Bureau. 2003. 2000 census of population and housing, summary social, economic, and housing characteristics, PHC-2-34. U.S. Government Printing Office, Washington, D.C., USA.

Van Brackle, M. D., R. L. Marchinton, G. O. Ware, V. F. Nettles, S. B. Linhart, C. R. Ruth, and L. O. Rogers. 1995. Oral biomarking of a supplementally-fed herd of free-ranging white-tailed deer. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 49:372–382.

Vogelmann, J. E., S. M. Howard, L. Yang, C. R. Larson, B. K. Wylie, and N. Van Driel. 2001. Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. Photogrammetric Engineering and Remote Sensing 67:650–652.

White, G. C. 1996. NOREMARK: Population estimation from mark-resighting surveys. Wildlife Society Bulletin 24:50–52.

Williamson, S. J. 2000. Feeding wildlife… just say no! Wildlife Management Institute, Washington, D.C., USA.

Wilson, D. E., F. R. Cole, J. D. Nichols, R. Rudran, and M. S. Foster. 1996. Measuring and monitoring biological diversity: standard methods for mammals. Smithsonian Institution, Washington, D.C., USA.

Paul D. Curtis (right in photo above) received a Ph.D. degree from North Carolina State University (1990), an M.S. degree from Colorado State University (1981), and a B.S. degree from West Virginia University (1978). He is currently an associate professor and extension wildlife specialist at Cornell University, and he has coordinated the wildlife damage management program there during the past 16 years. His research interests include wildlife damage management in urban and agricultural landscapes, wildlife fertility control, and resolving community-based wildlife issues. He serves as faculty advisor for the Cornell University student chapter of The Wildlife Society, and was a former chair of the TWS-Wildlife Damage Management Working Group.

Jason R. Boulanger (left in photo above) received a Ph.D. degree from Cornell University (2007), an M.S. degree from South Dakota State University (2001), and a B.S. from the University of Vermont (1995). He is an extension associate and deer program coordinator with the Department of Natural Resources (DNR) at Cornell University. Before coming to DNR, he was a wildlife biologist with the New York State Animal Health Diagnostic Center at Cornell University and a wildlife specialist with USDA Wildlife Services. His research interests include wildlife ecology, wildlife diseases, and human dimensions of wildlife. He is a certified wildlife biologist with The Wildlife Society.

Bazartseren Boldgiv received his Ph.D. degree in ecology and evolutionary biology from the University of Pennsylvania (2006), M.S. degree in wildlife science from Cornell University (2001) and B.S. degree in biology from National University of Mongolia (1995). He joined the National University of Mongolia as an assistant professor in 2006 and is currently heading the ecology program there. His research interests involve theoretical and applied aspects of dynamics of ecological systems. His current research interests include ecological and evolutionary effects of global change on an ecotonal region between boreal forest and steppe in Northern Mongolia.

Peter M. Mattison is a wildlife biologist and environmental consultant based in Seattle, Washington. His recent work includes monitoring bald eagle nests on U.S. Naval bases for signs of disturbance and employing infrared-triggered digital camera traps to measure wildlife exposure to toxic waters on abandoned mining sites. He has just returned from a 9-month stay in rural China, where he served as an assistant for an anthropological research project on the matrilineal Mosuo, taught English, and worked as a freelance photographer. He has a strong interest in conservation and natural resource stewardship, both at home and in developing nations, and continues to pursue opportunities to explore these areas.