

# Estimating sika deer abundance using camera surveys

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**Abstract** Cameras have been used throughout the world to estimate wildlife abundance and occupancy. Abundance estimates generated by camera surveys tend to be less invasive, less costly, and more accurate than other means in certain situations. We sought to expand and test the effectiveness of camera surveys on sika deer in Maryland. In 2008, we setup surveys with a 7-day pre-bait period followed by a 7-day active camera survey with 15 cameras. In 2009, we ran the cameras for the entire 14-day survey and moved cameras after each survey to determine if biases occur when using the same camera sites. During both years and all surveys, camera density was approximately 1-camera/65-ha. The abundance estimates were similar between years and estimators. In 2009, increasing photo intervals from 1-min to 5- and 10-min intervals reduced the number of pictures by 66 and 81%, respectively, while providing similar abundance estimates. We calculated the daily detection probabilities for all identifiable deer and we used radio-collared males that occurred within 2 km of the survey grid to assist in determining the optimum survey length. Detection probability did not vary between surveys in the same year, but varied between 2008 and 2009, most likely due to unlimited bait being available during 2008 surveys. Camera surveys have proven to be an accurate and cost effective means of estimating wildlife abundance and can be used successfully to determine sika deer abundance.

**Keywords** Camera survey · *Cervus nippon* · Photo intervals · Population estimate · Sika deer

## Introduction

Camera surveys have been used for multiple applications throughout the world, including estimating wildlife abundance, occupancy, and presence (Cutler and Swann 1999; Swann et al. 2004). White-tailed deer (*Odocoileus virginianus*) have been the primary focus when determining abundance in cervid populations (Jacobson et al. 1997; Koerth et al. 1997; Watts et al. 2008). The same techniques could be used to estimate sika deer (*Cervus nippon*) abundance, and using camera surveys to estimate abundance for sika deer could provide managers with a more refined tool. Sika deer in Maryland share a similar history with many introduced sika deer populations in Europe and New Zealand, a few individuals increase to a population that competes with and possibly excludes native species (McCullough et al. 2009). Maryland sika deer started with a founding population of 4 or 5 individuals (2 males and 2–3 females) and has grown into a population of approximately 10,000 (Flyger and Warren 1958; Feldhamer et al. 1978; Mullan et al. 1988; Feldhamer and Armstrong 1993; Maryland Department of Natural Resources, hereafter MD DNR, unpublished report). Research has documented sika deer competing with and excluding other ungulates, including white-tailed deer, axis deer (*Axis axis*) and roe deer (*Capreolus capreolus*) in Texas, New Zealand, and Great Britain (Cadman 1980; Bartos and Zirovnický 1982; Feldhamer and Armstrong 1993; Demarais et al. 2003). Eyler (2001) concluded that white-tailed deer and sika deer do not compete in Maryland due to differences in habitat use. However, sika deer have more diverse feeding habits

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and possess digestive systems that can utilize more nutrients from sub-optimal forage, giving them a competitive advantage when resources are limited (Feldhamer et al. 1978; Demarais et al. 2003).

Currently the MD DNR uses population reconstruction to estimate the sika deer population in Maryland (Downing 1980). In 2008, the MD DNR estimated the sika deer population to be 6,723 individuals (MD DNR, unpublished report). This estimate only reflects deer within the core of the occupied range due to limited hunter harvest on the edges. In order to estimate sika deer populations on the fringe of the core area, a population estimator needs to exist that does not rely solely on harvest.

Methods previously used to estimate sika deer abundance include: pellet counts, helicopter transects, herd composition counts (hereafter HCC), and mark-resight spotlight counts (Eyler 2001; Marques et al. 2001; Kaji et al. 2005; Sakato et al. 2009; Voloshina and Myskenkov 2009). In the United Kingdom and Japan, sika deer densities have been estimated using two variations of fecal pellet count surveys, but pellet groups are very difficult to distinguish when >1 species of deer is present, as is the case in most areas (Chadwick et al. 1996; Marques et al. 2001; Sakato et al. 2009). Helicopter surveys were used to estimate sika deer abundance in the Russian Far East, but these surveys tend to be limited to areas with unobstructed visibility (Voloshina and Myskenkov 2009). Additionally, scheduling conflicts often arise when trying to time helicopter surveys with uniform snowfall (Koerth et al. 1997; Beringer et al. 1998). Eyler (2001) used marked individuals during spotlight counts to estimate sika deer abundance on Tudor Farm LLC (hereafter, Tudor Farm) in Dorchester County, Maryland. He noted that spotlight counts were not precise because sika deer tend to use open areas less than white-tailed deer (Eyler 2001). Kaji et al. (2005) used HCC to provide an index of sika deer abundance, but the seasonal timing of the HCC was very important in determining precise sex and age ratios. Furthermore, the HCC counts were conducted on a relatively small, isolated area, 497.8 ha, which makes extrapolating estimates to larger geographic area difficult, especially when open viewing areas may be limited (McCullough 1982, 1993, 1994; Eyler 2001; Kaji et al. 2005). All previously listed methods can be costly and/or inaccurate and may not be applicable for areas of dense vegetation, often inhabited by sika deer (McCullough 1982, 1993, 1994; Koerth et al. 1997; Eyler 2001; Kaji et al. 2005; Watts et al. 2008).

Camera surveys provide an opportunity to allow researchers a hands-off approach to assess wildlife populations. The successful use of camera surveys to estimate deer populations make camera surveys a viable alternative to previously used sika deer estimation methods (Jacobson et al. 1997; Watts et al. 2008; Pei 2009; Curtis et al. 2009).

Camera surveys were previously used to estimate sika deer abundance in Kenting National Park, southern Taiwan, however the study relied on chance encounters, resulting in low photo-captures (Martorello et al. 2001; Pei 2009). Depending on survey objectives, camera surveys use either baited sites or chance encounters to determine species abundance (Bowman et al. 1996; Jacobson et al. 1997; Sweitzer et al. 2000; Roberts et al. 2006; Larrucea et al. 2007a, b; Pei 2009). Watts et al. (2008) expressed concerns regarding biases when conducting camera surveys that rely on bait, but baited camera surveys yield greater rates of photo captures than unbaited camera surveys and allows for easier identification of individuals (Bowman et al. 1996; Jacobson et al. 1997; McCullough et al. 2000; Sweitzer et al. 2000; Roberts et al. 2006; Larrucea et al. 2007a, b; Kelly et al. 2008; Watts et al. 2008; Pei 2009). Arguments might be posed that baiting could facilitate the spread of disease. Because of the relatively short duration of a camera survey (typically  $\leq 14$  days), the risk of exposure is fairly low. Additionally, camera surveys are much less invasive and stressful on deer than physical capture and can give much better estimates of population demographics.

Jacobson et al. (1997; hereafter the Jacobson method) and two estimators within program NOREMARK (Bowden and Minta & Mangel) have been used previously to generate estimates for deer abundance (Koerth et al. 1997; McCullough et al. 2000; Roberts et al. 2006; Ebersole et al. 2007; Watts et al. 2008; Curtis et al. 2009; Pei 2009). Program NOREMARK has also been used to analyze data collected from camera surveys conducted on populations of black bears in Arkansas; feral pigs (*Sus scrofa*) in northern and central California, and sika deer in Taiwan (Bowman et al. 1996; Sweitzer et al. 2000; Pei 2009). The Jacobson method can be applied to for sika deer due to the success demonstrated when estimating populations of white-tailed deer (Jacobson et al. 1997; Koerth et al. 1997; Roberts et al. 2006; Watts et al. 2008).

The two methods have slightly different approaches when generating population estimates. The Jacobson method uses a ratio based on the number occurrences of antlered individuals (antlered deer and/or tagged individuals), that ratio is then applied to antlerless/unidentifiable individuals. The Jacobson method assumes that there is an equal chance of individuals being resighted. The major disadvantage of using the Jacobson method is that it does not provide a confidence interval. Bowden's estimator assumes that the population is closed and uses the variance of sightings of marked individuals, and then applies the variance to the unmarked individuals to generate population estimates and confidence intervals (White 1996). Both estimators account for and recognize that not all individuals within the population are photographed during the

camera survey. We chose these two estimators because antlered deer can be used as the input data because once they are photographed once they are photo-captured and they can be continually photo-recaptured for the duration of the camera survey.

The effect of lengthening picture intervals on the abundance estimates generated from camera surveys has not been previously documented. Reducing the number of pictures reduces the cost associated with the survey and reduces the amount of time required to analyze photos. Refined camera survey techniques would allow researchers a more efficient and cost-effective survey with precise estimates. Additionally, the optimum survey length and detection probabilities should be determined for sika deer to verify camera survey effectiveness. In order to refine the camera survey methodology used to estimate sika deer abundance, our objectives were to: determine if sika deer population abundance could be estimated using data collected from camera surveys, determine if abundance estimates vary when increasing photo intervals, compare the effects of limiting bait during camera surveys, determine the optimum survey lengths for baited camera surveys, and determine the detection probability of sika deer during camera surveys.

## Methods

We chose Tudor Farm, an area in Dorchester County, Maryland because it provides a large, continuous property and is the approximate central point of the sika deer population in Maryland. The current range of sika deer in Maryland has an approximate land area of 1,000 km<sup>2</sup> (<http://www.dnr.state.md.us/greenways/counties/dorchester.html>) with elevations ranging from 0–2 m above sea level. During camera surveys, temperatures averaged 25°C and the average precipitation during both years was similar to the 20-year annual average of 109 cm ([http://mi.nws.noaa.gov/climate/local\\_data.php?wfo=akq](http://mi.nws.noaa.gov/climate/local_data.php?wfo=akq)).

The landscape was classified into three dominant habitat types: agricultural, forests and salt marsh. Primary agricultural crops are corn (*Zea mays*), wheat (*Triticum spp.*) and soybeans (*Glycine max*). Forests are categorized into two different types: lowland and upland. Lowland forests have high water tables with an overstory consisting mainly of loblolly pine (*Pinus taeda*) with interspersed willow oak (*Quercus phellos*) and sweet gum (*Liquidambar styraciflua*). The midstory and understory are mostly comprised of loblolly pine, sweet gum, sweetpepper bush (*Clethra alnifolia*), wax myrtle (*Myrica cerifera*), American holly (*Ilex opaca*), phragmites (*Phragmites australis*) and poison ivy (*Toxicodendron radicans*). Upland forests have a greater diversity of tree species that including: loblolly

pine, willow oak, northern red oak (*Q. rubra*), white oak (*Q. alba*), sweet gum, black gum (*Nyssa sylvatica*), American holly and American beech (*Fagus grandifolia*). The midstory of the upland forests primarily consists of red maple (*Acer rubrum*) and sweet gum with the understory being dominated by greenbrier (*Smilax spp.*) and poison ivy. Salt marsh vegetation consists primarily of salt grass (*Distichlis spicata*), black needlerush (*Juncus roemarianus*), Olney's three-square (*Scirpus americanus*), cordgrass (*Spartina spp.*), and phragmites (Eyler 2001).

We captured sika deer in 2008 between January and March and in 2009 between January and April. We used drop net, clover trap, and darting methods described by Rhoads et al. (2010) as the means of capture. After we captured sika deer in either a drop net or a clover trap we used xylazine hydrochloride (0.5 mg/kg) as the chemical restraint (Conner et al. 1987; Kilpatrick and Spohr 1999; Rhoads et al. 2010). While sedated, we fitted all sika deer with two medium plastic ear tags (white with black numbers, 4.5 × 5.1 cm, Allflex USA, Inc. Dallas, TX, USA) and two self-piercing metal ear tags (Model # 1005-49, National Band and Tag Company, Newport, KY, USA), which were uniquely numbered for each individual. Additionally, we fitted juvenile males with an expandable VHF radio-collar (340 g; Advanced Telemetry Systems, Isanti, MN, USA) with a mortality sensor. We used yohimbine hydrochloride (0.2–0.7 mg/kg) as the antagonist and observed the deer until they left the capture site unassisted (Mech et al. 1985; Conner et al. 1987; Rhoads 2006). We administered vitamin E (30 U/kg of body weight; Eyler 2001; Rhoads 2006; Rhoads et al. 2010) to all deer that showed signs of capture myopathy (Beringer et al. 1996). The University of Delaware's Institutional Animal Care and Use Committee (IACUC) approved all capture and handling procedures, approval number 1182.

We conducted camera surveys in July and August during 2008 and 2009 when antler growth was nearly complete, allowing for the best recognition of individual male sika deer and prior to the start of hunting season (Jacobson et al. 1997). We set infrared-triggered motion-sensing, digital trail cameras (Cuddeback Excite, Non Typical Inc., Park Falls, WI, USA; hereafter, cameras) to take pictures at one-min intervals and positioned them approximately 3 m from the bait allowing for a full size image of the deer to be taken. We checked each camera site daily, replenishing bait, batteries, and memory cards as needed.

In 2008, we conducted two separate 14-day camera surveys. The camera surveys consisted of a 7-day pre-bait period followed by a 7-day active camera period. After the first survey there was a 7-day period where all bait was removed and then the second survey was initiated at the same site. In order to establish camera sites, we collected GPS locations of sites used annually for recreational

hunting. Then using ArcView 3.2 (ESRI Inc., Redlands, CA, USA), we chose 15 camera sites spaced to represent  $\approx 65$  ha for a total coverage area of 975 ha.

We started with 4 kg of whole kernel corn per site and maintained that amount until all bait was consumed in 1 day. Once the bait placed at the site was consumed in a single day we increased the total amount placed at the site, by two fold. We continued increasing bait until deer were unable to consume it in a single night at which time that amount was maintained for the remainder of the survey, bait place at sites ranged from 4 to 35 kg. Allowing an unlimited amount of bait at camera sites allowed for all deer wanting to visit the camera site to be photographed prior to bait depletion while minimizing the amount bait of lost to decomposition.

We altered the survey methods in 2009 due to an increase in picture occurrences between the 1st and 2nd camera surveys in 2008. The increase in occurrences we initially attributed to using the same camera site for consecutive surveys. In 2009, we conducted two surveys with an active camera for the duration of the 14 days. To eliminate any potential bias by using the same bait sites for consecutive surveys we separated individual camera surveys by 7 days and moved the camera sites approximately 200 m northeast. We divided a 1,365 ha grid into 21, 65-ha cells. Within 200 m of the center of each grid cell, we placed one camera. At the camera site, we maintained 13 kg of shelled corn for the duration of the 14-day survey. By limiting the amount of bait placed at each site, we hoped to reduce the amount of corn used throughout both surveys and reduce the overall cost of the camera surveys.

Once surveys were complete, we separated photographs by camera site, day, survey number, and year. We counted all deer within each picture, tallying occurrences of identifiable individuals separately from individuals that were indistinguishable. The categories we used were: branched-antler deer, ear-tagged deer, unbranched-antler deer, antlerless deer, and juveniles. All deer that we could not identify by antler characteristics or ear tags were lumped together in their respective category. We used these data to generate abundance estimates for individual surveys and picture intervals using both the Jacobson method and Bowden's estimator (Jacobson et al. 1997; Koerth et al. 1997; Sweitzer et al. 2000; Watts et al. 2008; Curtis et al. 2009). After determining the abundance estimate for the respective camera survey we calculated the density. We did this by dividing by the survey coverage area by the total abundance estimate. In 2008, the total coverage area was 975 ha and in 2009 the total coverage area was 1,365 ha. Each camera bait site had an approximate coverage area of 65 ha, based on the optimum coverage area determined by Jacobson et al. (1997).

In 2009, after calculating abundances for both surveys using pictures taken at 1-min intervals, we removed

pictures that did not occur  $\geq 5$  and  $\geq 10$  min from the preceding picture. After we limited the pictures to those taken at 5- and 10-min intervals, we used Bowden's estimator and the Jacobson method to generate additional population estimates. We then compared the 95% confidence interval overlap generated by Bowden's estimator to make inferences about the estimates.

For all surveys we noted the first day that identifiable individuals occurred at camera sites in order to determine the optimum survey length. We then plotted the survey days against the day that individual deer occurred at camera sites to determine the optimum survey length. We determined the detection probabilities for identifiable males, ear-tagged females, and radio-collared males by adding the total number of days detected per deer and dividing by the total number of active camera days.

To calculate detection probability by distance, we located radio collared yearling males within 2 km of the camera grid once daily during active camera days using 2 compass bearings, taken within 15 min, from fixed points on the landscape. We used the bearings as input data for program LOAS (Location of a Signal; Ecological Software Solutions, LLC) to calculate deer locations. We collected all locations during midday (between 1000 and 1400 hours) when deer were least active (Kalb 2010). We measured the distance from each deer's daily location to the nearest eight camera sites by limiting the number camera sites used in the analysis removed all sites that were unlikely to be visited by deer on a daily basis. We used SAS (version 9.2; SAS Institute, Cary, NC, USA) to develop a logistic regression model of detection probability as a function of distance to a camera site. The model permitted us to assess the likelihood of camera site visitation based on distance to determine if grid cell size was adequate.

## Results

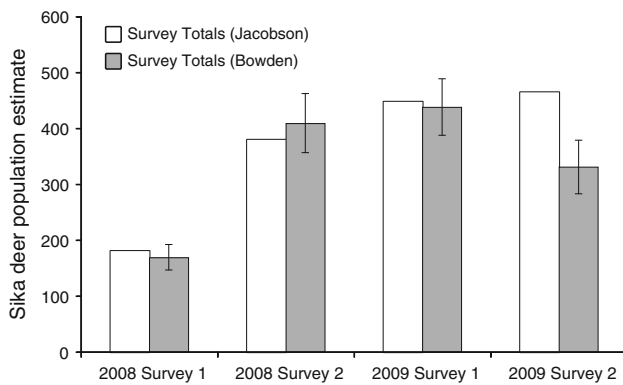
In 2008, we captured 51 sika deer: 21 juvenile males, 18 adult females and 12 juvenile females. We collected 18,354 photographs of sika deer during both camera surveys, taken at 1-min picture intervals (Table 1). The 2008 camera surveys yielded a total of 83 identifiable deer: 64 males (branched antlers), 10 adult females (ear tagged) and 8 radio-collared males (ear tagged; Table 1). The Survey 1 estimate was approximately half the amount of the Survey 2 estimate, but the population estimates generated by the Jacobson method and Bowden's estimator were similar in their respective survey (Fig. 1). Density estimates ranged from 17 to 42 deer/km<sup>2</sup> with an average of 33 deer/km<sup>2</sup> for both surveys and both estimators.

In 2009, we captured 67 sika deer: 4 adult males, 24 juvenile males, 12 adult females and 27 juvenile females.

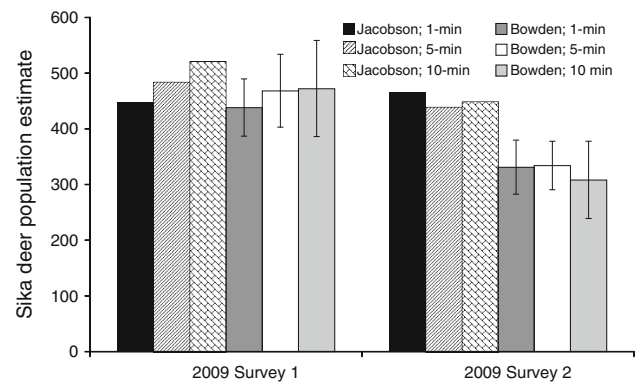


**Table 1** Summary of photo captured unique adult male, tagged female, and radio-collared male sika deer at Tudor Farm LLC in Dorchester County, Maryland

	2008 Survey 1	2008 Survey 2	2008 Totals	2009 Survey 1	2009 Survey 2	2009 Total
Adult males	29	35	64	75	55	133
Tagged females	6	6	10	21	11	26
Radio-collared males	4	6	8	11	4	12
Photos taken						
1-min	8,233	10,121	18,354	18,578	15,301	33,879
5-min	–	–	–	6,332	5,215	11,547
10-min	–	–	–	3,527	2,905	6,432
Sex ratio (female:male)	1:01	3:01	–	2:01	3:01	–



**Fig. 1** Population estimates for sika deer during four separate camera surveys using the Jacobson method and Bowden’s estimator within program NOREMARK at Tudor Farms, LLC in Dorchester County, Maryland during 2008 and 2009. Jacobson method estimates do not include error bars because this method does not calculate standard errors of the estimates



**Fig. 2** Population estimates for sika deer during two camera surveys using the Jacobson method and Bowden’s estimator within program NOREMARK for 1-, 5- and 10-min picture intervals at Tudor Farms, LLC in Dorchester County, Maryland during 2009. Jacobson method estimates do not include error bars because this method does not calculate standard errors of the estimates

We collected 33,879 photographs at 1-min picture intervals and identified 171 individuals: 133 males (branched antlers), 26 adult females (ear tagged) and 12 radio-collared males (ear tagged; Table 1). Increasing the photo intervals reduced the total number of pictures taken at 5-min intervals by 66% and pictures taken at 10-min intervals by 81% (Table 1). Abundance estimates generated by both estimators were similar in all surveys, with the exception of Survey 2 (Fig. 2). The estimates were less in Survey 2 because of greater variance of occurrences of identifiable individuals during the survey (Fig. 2). The abundance estimates for 1-, 5-, and 10-min picture intervals generated by the Jacobson method and Bowden’s estimator were similar within the estimators but varied between the estimators (Fig. 2). The 95% confidence intervals generated by Bowden’s estimator overlapped, but the estimates generated by the Jacobson method were greater than the upper limits of Bowden’s estimates in every survey (Fig. 2). Sika deer density estimates for both surveys were also similar for both estimators ranging from 32 to 35 deer/km<sup>2</sup> with an average of 32 deer/km<sup>2</sup> (Table 2).

The detection probabilities varied little during surveys within the same year; but the detection probabilities were greater in 2008 than 2009 (Table 3). The length of time that elapsed before a deer was detected at bait sites varied between years (Figs. 3, 4, 5). Individual deer were detected earlier in the surveys in 2008 than in 2009, regardless of sex or age (Figs. 3, 4, 5). The detection of available radio-collared male sika deer was also greater in 2008 than in 2009 (Fig. 5). The detection probability of radio-collared male sika deer at 0 m was 26% ( $\chi^2_1 = 36.254, P < 0.001$ ), 7% ( $\chi^2_1 = 26.513, P < 0.001$ ), and 11% ( $\chi^2_1 = 59.605, P < 0.001$ ), in 2008, 2009, and both survey years combined, respectively.

**Discussion**

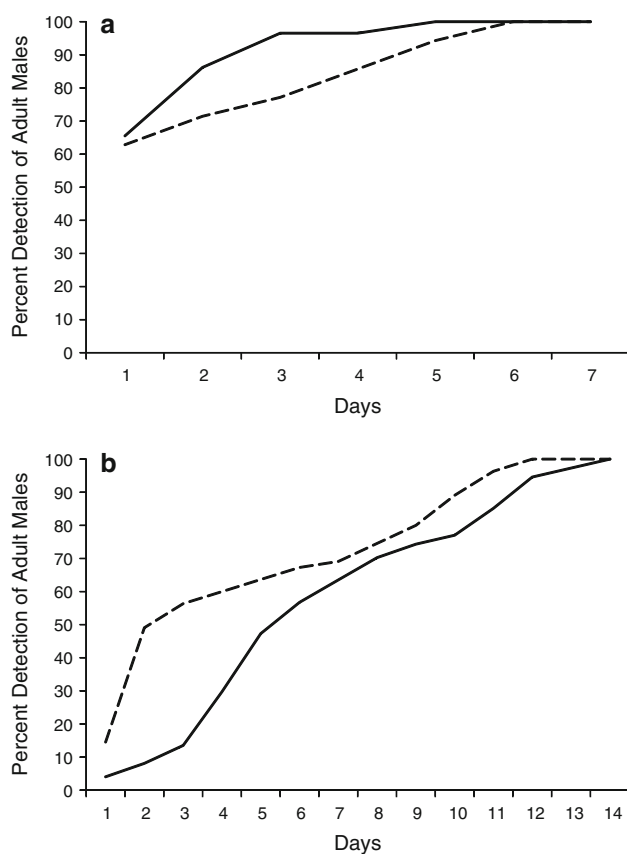
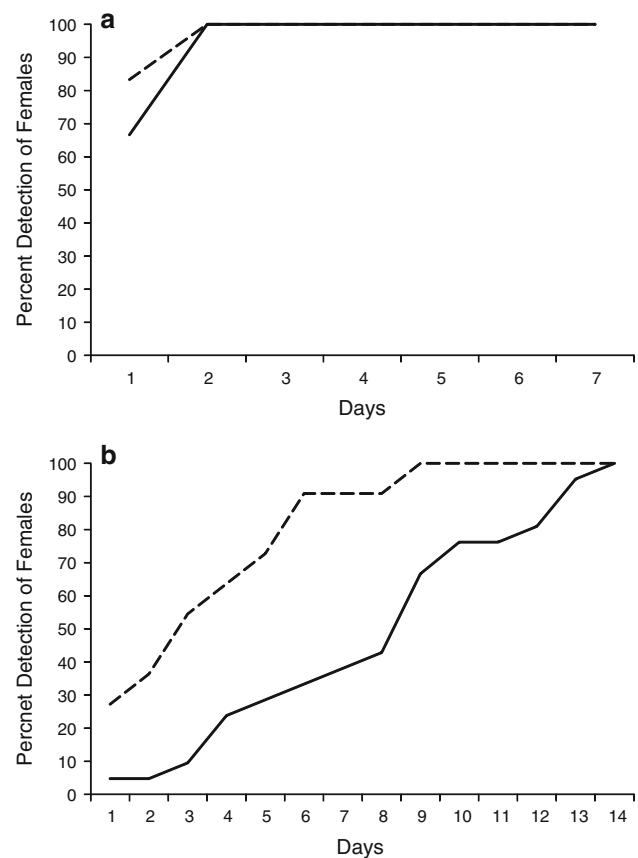
The estimates generated from the camera surveys were similar within surveys with the exception of Survey 2 in 2009. In that survey the abundance estimates generated by Bowden’s estimator (331, 334, and 308 deer; 1-, 5-, and

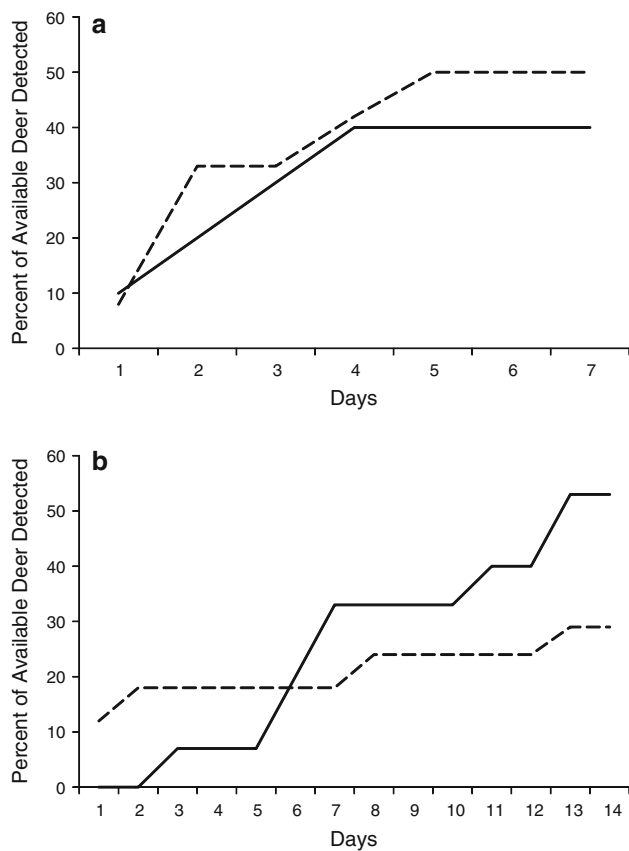
**Table 2** Sika deer densities by survey number, estimation method ( $\pm 95\%$  CI for Bowden estimator) and picture interval at Tudor Farm LLC in Dorchester County, Maryland during 2008 and 2009 camera surveys

	2008 Survey 1	2008 Survey 2	2009 Survey 1	2009 Survey 2	Average density
Jacobson; 1-min	19	39	33	34	31
Jacobson; 5-min	–	–	35	32	34
Jacobson; 10-min	–	–	38	33	36
Bowden; 1-min	17 ( $\pm 2.4$ )	42 ( $\pm 5.4$ )	32 ( $\pm 3.7$ )	24 ( $\pm 3.5$ )	29 ( $\pm 3.6$ )
Bowden; 5-min	–	–	34 ( $\pm 4.8$ )	24 ( $\pm 3.2$ )	29 ( $\pm 4.0$ )
Bowden; 10-min	–	–	35 ( $\pm 6.3$ )	23 ( $\pm 5.1$ )	29 ( $\pm 5.7$ )

**Table 3** Detection probability (95% CI) of sika deer by sex and age classes based on the number of days detected during 4 separate camera surveys in 2008 and 2009 at Tudor Farm LLC in Dorchester County, Maryland

	2008 Survey 1	2008 Survey 2	2009 Survey 1	2009 Survey 2
Adult males	0.709 ( $\pm 0.10$ )	0.551 ( $\pm 0.10$ )	0.346 ( $\pm 0.05$ )	0.340 ( $\pm 0.06$ )
Tagged females	0.762 ( $\pm 0.24$ )	0.714 ( $\pm 0.27$ )	0.333 ( $\pm 0.10$ )	0.461 ( $\pm 0.14$ )
Radio-collared males	0.714 ( $\pm 0.37$ )	0.548 ( $\pm 0.31$ )	0.279 ( $\pm 0.16$ )	0.536 ( $\pm 0.40$ )

**Fig. 3** Percentage of unique sika deer adult males detected by day during two different camera surveys in 2008 (a) and two different camera surveys in 2009 (b) at Tudor Farm in Dorchester County, Maryland. *Solid line* is survey 1 and *dashed line* is survey 2**Fig. 4** Percentage of tagged sika deer yearling and adult females detected by day during two different camera surveys in 2008 (a) and two different camera surveys in 2009 (b) at Tudor Farm in Dorchester County, Maryland. *Solid line* is survey 1 and *dashed line* is survey 2



**Fig. 5** Percent of available juvenile sika deer males detected during 2008 (a) and 2009 (b) camera surveys by day and survey at Tudor Farms, LLC in Dorchester County, Maryland. *Solid line* is survey 1 and *dashed line* is survey 2

10-min intervals, respectively) are less than the estimates generated by the Jacobson method (448, 468, and 521; 1-, 5-, and 10-min intervals, respectively). The upper limits of the confidence intervals from Bowden's estimates do not overlap the estimates generated by the Jacobson method. However, considering the small differences between the estimates from all other surveys, there seems to be no discernable difference between estimates generated by either the Jacobson method or Bowden's estimator. The only inconsistent estimate during the entire study was Survey 1 in 2008. The estimates in this survey were nearly half the total population estimates generated in the second Survey 2 in 2008 and both surveys in 2009 (Table 2; Figs. 1, 2). The lower estimates in 2008 during Survey 1 were probably a result from fewer individual deer being identified and fewer photos being taken (Table 1). Density estimates were most likely not biased by the use of bait at camera sites. It has been documented that deer will travel substantial distances when desirable forage is available (Campbell et al. 2006). By converting the abundance estimates to density estimates managers can extrapolate those estimates to a much larger area, making all estimates

much more useful for wildlife managers. Program NO-REMARK has one major limitation when dealing with a large numbers of occurrences; the greatest value that can be input is 9,999. No previous research has reported this problem; however, no other research has reported the high number of occurrences as observed in our study (Bowman et al. 1996; Sweitzer et al. 2000; Roberts et al. 2006; Watts et al. 2008; Pei 2009). Considering the similarity between estimates generated by the Jacobson method and Bowden, the estimators could be used interchangeably based on the camera survey objectives and the anticipated number of occurrences; however the Jacobson method is unable to generate confidence intervals making this estimator less beneficial to wildlife managers.

Cost reduction is often a major concern when conducting population surveys (Jacobson et al. 1997; Koerth et al. 1997; McKinley et al. 2006; Roberts et al. 2006; Watts et al. 2008; Curtis et al. 2009). Increasing the picture intervals from 1 to 5 min and 10 min had little effect on the population estimate except that Bowden's 10-min estimates generated much wider confidence intervals (Fig. 2). The greatest savings from increasing the photo interval comes from photo analysis. In our study, increasing the photo interval reduced the total number of photos by 66 and 81% for pictures taken at 5- and 10-min intervals, respectively (Table 2). When analyzing photos, it took an average of 1-h to analyze 120 photos, for a total time of  $\approx 282$ -h for photos taken at 1-min intervals. By increasing the photo interval to 5-min the total time required to analyze all photos was  $\approx 96$ -h and increasing the photo interval to 10-min total time was reduced to  $\approx 53$ -h. Additionally, by increasing the photo intervals, camera surveys would use fewer batteries, require fewer pictures to be developed (if film cameras were used), and require less effort on behalf of the surveyor.

Curtis et al. (2009) stated that camera surveys would cost approximately \$26/ha based on a total survey cost of \$6,951. However, Curtis et al. (2009) used film cameras that resulted in an extra cost of \$550 and they used TRAILMASTER camera systems (Goodson and Associates, Inc., Lenexa, KS, USA) which resulted in a cost of \$507 per unit. In contrast, Jacobson et al. (1997) and Koerth et al. (1997) had costs of \$5/ha and \$2/ha, respectively, and our study resulted in a cost of \$6.90/ha, \$5.86/ha and \$5.56/ha for 1-, 5- and 10-min cameras surveys, respectively. Our study costs were based on a cost of \$300 per camera, \$20 for two memory cards and \$8/h for research technicians. Our study resulted in a lower cost than Curtis et al. (2009) because the camera units we used were less expensive and we did not have to pay to process film, which reduce the overall cost, especially when surveying larger areas. The majority of studies utilizing camera surveys used TRAILMASTER camera systems for

their reliability, but given the technological advancements in other remote sensing infrared camera systems and their reduced cost, they could be used in place of the TRAILMASTER systems. Aside from the additional cost of the TRAILMASTER systems, they use film cameras which increase the overall survey cost, and those systems have a limited number of photos they can take during a day, where as remote cameras taking digital photos can take an unlimited number of photos depending on the capacity of the memory card.

Survey lengths of 14 days have been determined to be the optimum length of time needed to assess all deer within the survey area (Jacobson et al. 1997; Watts et al. 2008). Based on the days to detection and the detection probabilities for 2008 and 2009, the amount of bait placed at sites plays a key role in determining the optimum survey length (Figs. 3, 4, 5). Limiting bait increased the competition for bait and therefore increased the amount of time needed for deer to be detected (Figs. 3, 4, 5). In 2008 when bait was not limited, all deer were detected by day 3 during the active camera period (equivalent of day 10 in a 14-day survey); however in 2009, not all deer were detected until day 13 (equivalent of day 6 for a 7-day survey). The lower detection rates of available juvenile males in 2009 further supports that limiting bait reduces the overall attractiveness of bait sites (Fig. 5). When bait is available for longer periods sika deer have more time to be detected at bait sites and also more time during the day to approach baited sites, increasing detections. Limiting bait at sites reduces the bait availability to any deer in the area and increases competition for available bait.

As with Jacobson et al. (1997), 14 days was the optimal amount of time for sika deer using sites with limited amounts of bait. Allowing an unlimited amount of bait to be available to sika deer would permit shorter camera surveys. Based on the surveys that we conducted in 2008, all sika deer were consistently detected by the tenth overall day of the survey (Figs. 3, 4, 5). A 10-day camera survey appears to be the optimum length of time if bait is unlimited.

Limiting the amount of bait placed at camera sites also plays a role in the detection probabilities of deer at bait sites. In 2008 both surveys had greater detection probabilities than either survey in 2009. Additionally, in 2008 Survey 1 had greater detection probabilities than Survey 2 in all categories demonstrating that using the same camera site had no effect on the camera surveys. Sika deer have been documented to have sporadic movements throughout their introduced and native ranges making it difficult to determine detection probability (Feldhamer et al. 1982; Bartos 2009; Swanson and Putman 2009; Torii and Tatsuzawa 2009; Kalb 2010). To compensate for random movements camera site selection becomes very important,

but the amount of bait placed at camera sites played a greater role in the overall attractiveness of camera sites (Bartos 2009; Swanson and Putman 2009; Torii and Tatsuzawa 2009). Despite the potential for biases associated with using bait to conduct camera surveys as noted by Watts et al. (2008), the use of baited camera sites greatly increased detection of sika deer and decreased the width of confidence intervals when compared to unbaited camera surveys (Pei 2009) and therefore should be preferred over unbaited camera surveys.

## Summary

Camera surveys can be a valuable tool for researcher and wildlife managers. They provide an accurate and cost effective means of assessing age, sex, and abundance of wild deer populations without having to capture deer. A camera survey with photos taken at 1-min photo intervals provides the best estimate and tightest confidence intervals, but budget minded managers can obtain similar results and reduce camera survey cost by increasing the photo interval to 5 min. Camera survey techniques have not been completely refined, but camera surveys are less invasive and more accurate than other previously described methods.

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